ГЕОМЕХАНИКА. РАЗРУШЕНИЕ ГОРНЫХ ПОРОД

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Preliminary softening of frozen overburden in the course of open-pit mining of mineral deposits of the North

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Abstract

Relevance. *Blastless loosening and recovery of frozen rocks and coals is impeded by their significant excavation resistance, which implies the need for rock softening. Surfactants might be a solution. In permafrost conditions, the main difficulties occur in winter when developing the uppermost active layer, which is most frozen during a winter season. Softening can provide optimal conditions for its development. To increase the efficiency of frozen rock softening, it is proposed to use a device (a utility model) developed by N. V. Chersky Mining Institute of the North of the Siberian Branch of RAS.*

Research objective *is to substantiate the mechanism of the proposed utility model. The technical task of the proposed utility model is to soften the frozen rocks under continuous penetration of surfactant into cracks and pores of the rock mass due to the hydrostatic pressure in order to increase the efficiency of stripping operations in coal mines in the permafrost zone.*

Research results. *A device for continuous preliminary softening of frozen rocks around a drilled downward vertical borehole consists of a hollow cardboard cylinder and a sealed capsule inside, filled with a surfactant (15–75% solution of NaCl), the cylinder has a neck to fit in the wellhead inside the well. To ensure stable continuous penetration of the solution through cracks and pores in the mass due to hydrostatic pressure inside the well, the sealed capsule has a volume exceeding the volume of the well by at least three times, and the height of the cylinder is not less than twice its diameter. To ensure uniform flow of solution into the well, the neck is equipped with a perforated dispenser, a valve is installed in the upper part of the cylinder to balance the pressure with atmospheric air, and the lower part is sprinkled with drill fines to give additional stability.*

Conclusions. *The proposed utility model for frozen overburden preliminary softening by aqueous surfactant solutions when mining solid minerals of the permafrost zone by an open method will lead to changes in their strength and deformation properties, which allows, within certain limits, to control the state and properties of the rock mass.*

Keywords: *frozen rocks; surfactant solution; borehole; rock mass cracks; rock mass pores; blastless technologies; softening; surfactants.*

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Introduction. Blastless technologies are relevant when developing frozen ground in coal, diamond and other deposits [1, 2]. Currently, Wirtgenu, VASM, [3–6] and KSM layer-by-layer cutting machines have become widely used in open pits. The layer-by-layer cutting machines can develop rock masses with a uniaxial compressive strength of up to 120 MPa and provide high selection of thin layers without preliminary drilling and blasting or mechanical preparation for recovery.

Research results presented in [7] proved the potential of blastless development of rock and coal at the Elginsky coal deposit by the continuous flow technology based on rotary conveyor lines and KSM-type continuous miners. Calculations showed the dependence between the capacity of the KSM-2000R miner and the physical and mechanical properties of various rocks at the deposit. It has been established that the KSM-2000R capacity for coal and carbonaceous siltstones with a compressive strength of up to 40 MPa (17% of gross rock volume in the deposit) in a dense body is 1400 m^3/h; for overburden rock with a strength of 40 to 60 MPa (35%) the capacity is 1000 m^3/h; and for overburden rock with a strength of from 60 to 80 MPa the capacity is 650 m^3/h. Thus, as rock strength increases, the mining machine's capacity decreases significantly, especially in winter. Significant excavation resistance of frozen rock necessitates their softening to ensure blastless excavation. Surfactants might be a solution [8–11]. In permafrost conditions, the main difficulties occur in winter when developing the uppermost active layer. Its softening can provide maximum output of the mining machine since research results showed that surfactants significantly reduce the strength of frozen rock, and the higher the solution concentration, the more intense the rock softening.

Article [12] presents the findings of experimental study of strength characteristics of frozen dispersive soil samples (sand and loam) treated with a surfactant solution (2% polyvinyl alcohol). The strength characteristics of the samples were determined using the ball stamp method under constant load. The study showed that the introduction of surfactants has a softening effect on frozen soils despite their type. Moreover, it was established that changing frozen soil strength (both sands and loams) is a result of structural changes caused by surfactants introduction. The method of physical and chemical softening of rock and coal masses was successfully tested at the Taldinsky open pit (Kuzbass) in 1994–1996. The rock mass to be stripped was drilled with boreholes up to 1.0 m deep and 160 mm in diameter, with a 1.3×1.3 m borehole grid. The drilled boreholes were filled by gravity with an aqueous surfactant solution to their full depth. Within two days after the initial filling of the boreholes, the rock layer that was mined by a KSM-2000R miner was saturated. Positive results were obtained as the output of coarse-grained geomaterial was significantly reduced and excavation energy intensity was significantly reduced (by 23% on average) [13, 14].

N. V. Chersky Mining Institute of the North of the Siberian branch of RAS established experimental change dependencies for the strength of frozen fine sandstones under the effect of distilled water and NaCl solution of various concentrations in the sub-zero temperature range. Therefore, when softening rock with the compressive strength from 60 to 80 MPa, the capacity of KSM-2000R can increase from 750 to 1100 m^3/h (80% of the rated capacity) due to the use of surfactants, while for the coal of the Elginsky coal deposit it will be within the rated capacity (1400 m^3/h). The obtained results are of great practical importance for the development of technological measures to reduce the strength of permafrost rocks and increase the efficiency of their development [15]. Earlier, N. V. Chersky Mining Institute of the North carried out a research to determine the compressive strength of frozen sandstone samples from the Kangalas brown coal deposit saturated with brines from mineralized underground waters of ALROSA's Udachny kimberlite pipe having a freezing temperature of –20° C. The 50×50×50 mm cubic samples were prepared with 50% and 30% brine content of the total moisture content of the sandstone. The studies were conducted at temperatures from –5 to –40 °C on a UTS-250 testing machine. The test results showed that under a sample temperature of –40 °C, sandstone saturated with a 50% brine has a strength of 0.761 MPa, while the 30% brine at the same temperature has a strength of 0.933 MPa. It was found that at freezing temperatures from –5 to –30 °C, brine-containing samples scarcely adfreeze. This leads to conclude that under a more concentrated brine in the sample, its strength characteristics are significantly reduced [16].

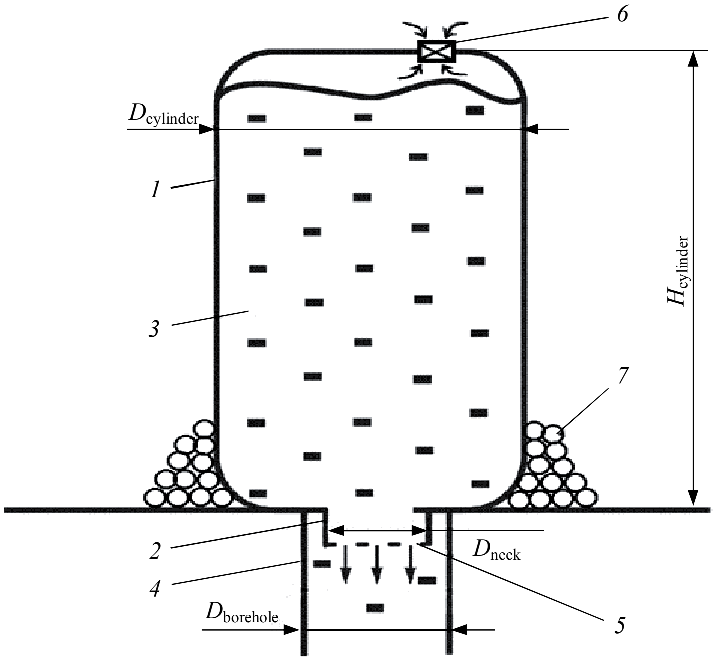

Figure 1. Device for continuous preliminary softening of frozen rocks around a borehole: *1* – cylinder; *2* – neck; *3* – surfactant solution; *4* – borehole; *5* – perforated dispenser; *6* – pressure balance valve; *7* – drill fines; $D_{cylinder}$, $H_{cylinder}$ – diameter and height of the cylinder; $D_{borehole}$, D_{neck} – diameter of the borehole and neck

Рисунок 1. Устройство для непрерывного предварительного разупрочнения мерзлых горных пород вокруг скважины: *1* – цилиндр; *2* – горловина; *3* – раствор ПАВ; *4* – скважина; *5* – перфорированный дозатор; *6* – клапан выравнивания давления; *7* – буровая мелочь; $D_{cylinder}$, $H_{cylinder}$ – диаметр и высота цилиндра; $D_{borehole}$, D_{neck} – диаметр скважины и горловины

V. I. Shtele invented a device [17] which determines the temperature of frozen rocks interval by interval along the borehole height. In the intervals, hydraulic fracturing is carried out by injecting hydrochloric acid, the concentration of which is changed in inverse relation to the temperature values to reduce the costs of frozen rock softening. Rocks weaken due to the mechanical effect of hydraulic fracturing and the chemical effect of hydrochloric acid. High costs are the disadvantage, since a solution of hydrochloric acid with a constant concentration is injected into different sections of the boreholes, which increases its consumption.

Thus, the experience of using aqueous solutions of surfactants has shown that their safety and ecological friendliness allow extended application in the course of open-pit mining in the permafrost zone. Even a relatively small introduction of aqueous solutions of surfactants in a solid rock mass will significantly reduce rock strength, and therefore, reduce the wear of the mining machine's cutting tool. This may justify the costs of early physical and chemical processing of the rock mass. It is reasonable to say that the use of surfactants aimed at reducing the strength of frozen overburden rocks in the permafrost zone deposits will make blastless mining with KSM-type mining machines possible.

Preliminary softening of frozen rock. Drilling and blasting operations are carried out to loosen frozen overburden rock in coal open pits in the permafrost zone. Subsequent excavation of blasted rocks in collapse is complicated by their repeated adfreezing, which complicates further mining by mining machines. There are devices and methods to prevent repeated adfreezing of blasted frozen rock [18]. A device developed at the Institute of Northern Mining is proposed for practical implementation. The device is intended for frozen overburden preliminary softening in the course of open-pit mining of mineral deposits in the North [19].

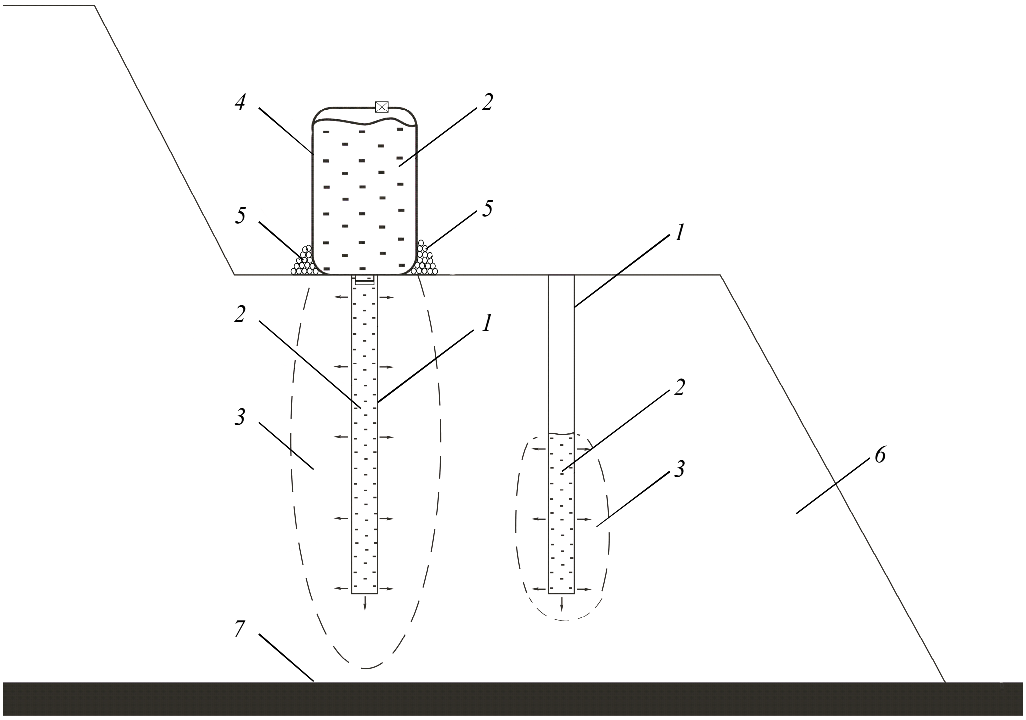

Figure 2. Layout of the device for continuous preliminary softening of frozen rocks around the borehole: *1* – borehole; *2* – surfactant solution; *3* – affected area; *4* – cylinder; *5* – drill fines; *6* – bench; *7* – soil
Рисунок 2. Схема расположения устройства для непрерывного предварительного разупрочнения мерзлых горных пород вокруг скважины: *1* – скважина; *2* – раствор ПАВ; *3* – зона воздействия; *4* – цилиндр; *5* – буровая мелочь; *6* – уступ; *7* – почва

The gist of the device (utility model) is in frozen rock softening by continuous penetration of solution into cracks and pores of the rock mass due to its own hydrostatic pressure. The utility model is shown in Figure 1.

A 15–75% NaCl softening solution is introduced into a borehole drilled in a frozen overburden rock mass. It has a thawing effect and begins to penetrate through cracks, voids and pores into the rock mass, interact with ice, and change the phase equilibrium of the ice–water–salt system through diffusion. As a result, a zone of softened rocks is formed around the borehole.

As the need arises, a 15–75% NaCl solution is added to the borehole, and a cylinder in the form of a sealed capsule is installed in its wellhead, the cylinder has a neck with a perforated dispenser to fit in the wellhead inside the well (Figure 2).

The cylinder is afterwards filled with a 15–75% NaCl solution and sprinkled with drilling fines to ensure vertical stability. Due to the additional hydrostatic pressure P_{cylinder} equal to the weight of the full cylinder, the solution will more actively and continuously penetrate into the frozen rock mass and soften it nevertheless, thereby increasing the softened frozen rock zone around the borehole. The proposed device will intensify preliminary softening of the frozen overburden rock in the course of open-pit mining of permafrost zone deposits due to the effect of aqueous solutions of surfactants. It will also help to control the state and properties of the rock mass, within certain limits.

Conclusions. The advantages of the proposed utility model are as follows: no need for expensive and dangerous blasting operations and acquisition of explosives, continuous uniform flow of the surfactant solution into the borehole through the perforated dispenser in the neck of the device, saving solution due to the presence of the perforated dispenser which prevents the solution from overflowing the borehole, no need for repeating addition of solution into the borehole (reducing the operation) and no need for the constant presence of people on the bench for adding the solution, and increasing the capacity of mining equipment.

Summary. The findings have shown that the effectiveness of surfactant solutions for frozen rock softening allows for the rock mass state and properties control, within certain limits. To increase the mining machines capacity, it is recommended to feed softening solutions directly to the cutting zone.

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Предварительное разупрочнение мерзлых вскрышных пород при разработке месторождений полезных ископаемых Севера открытым способом

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Реферат

Актуальность. *Значительное сопротивление копанию мерзлых пород и углей диктует необходимость их разупрочнения для обеспечения возможности безвзрывного рыхления и выемки. Возможным решением этого вопроса может быть использование поверхностно-активных веществ (ПАВ). Основные затруднения в условиях криолитозоны наблюдаются в зимнее время при разработке самого верхнего, наиболее промерзшего в зимний период деятельного слоя пород. Оптимальные условия для разработки можно обеспечить за счет разупрочнения, для повышения его эффективности предлагается использовать устройство – полезную модель, разработанную Институтом горного дела Севера Сибирского отделения РАН.*

Цель исследований *– обосновать принцип действия предлагаемой полезной модели. Ее технической задачей является разупрочнение мерзлых пород при непрерывном проникновении раствора ПАВ в трещины и поры горного массива за счет гидростатического давления для повышения эффективности ведения вскрышных работ на угольных разрезах криолитозоны.*

Результаты исследований. *Устройство для непрерывного предварительного разупрочнения мерзлых горных пород вокруг пробуренной нисходящей вертикальной скважины состоит из полого картонного цилиндра с размещенной внутри него герметичной капсулой с ПАВ (раствор NaCl в концентрации 15–75 %), цилиндр выполнен с горловиной для размещения его в устьевой части внутри скважины. Для обеспечения устойчивого непрерывного проникновения раствора по трещинам и порам в массиве за счет гидростатического давления внутри скважины объем герметичной капсулы превышает объем скважины не* *менее чем в три раза, а высота цилиндра не менее чем в два раза больше его диаметра. Для равномерного поступления раствора в скважину горловина снабжена перфорированным дозатором, в верхней части цилиндра установлен клапан для уравновешивания давления с атмосферным воздухом, а нижняя часть для придания дополнительной устойчивости присыпана буровой мелочью.*

Выводы. *Предложенная полезная модель предварительного разупрочнения мерзлых вскрышных пород при открытой разработке месторождений твердых полезных ископаемых криолитозоны за счет воздействия водных растворов ПАВ на горные породы обеспечивает изменение их прочностных и деформационных свойств, что позволяет в определенных пределах управлять состоянием и свойствами горного массива.*

Ключевые слова: *мерзлые горные породы; раствор ПАВ; скважина; трещины массива; поры горного массива; безвзрывные технологии; разупрочнение; поверхностно-активные вещества.*

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