Код МРНТИ 52.13.23

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MINE WORKINGS SUPPORTING TECHNOLOGIES ON STRESS AND STRAIN STATE CONTROL BASIS

Abstract. The development and pilot testing of high-tech resource-saving methods and active means of securing workings and stabilizing the rock mass is still relevant in the coal industry, taking into account the high technical and economic effect and improving the safety of mining operations. To maintain development workings in front of the longwall, accessible domestic technologies are being developed based on the management of the stress-strain state of the near-contour rock mass. This review provides an opportunity to: analysis of the practical use of anchoring and resin fixing compounds in coal mines; study of the parameters of deformation processes in mine workings; establishing the influence of anchoring technology on the operational characteristics of a mine working.

Key words: *zone of manifestation of increased rock pressure, technological schemes, support, reference pressure, anchor support resistance, roof displacement, mine workings, study of deformation processes, supporting parameters, coal mining.*

Кернеулі-пішіні өзгерген күйде бақылауға негізделген тау-кен қазбаларын бекіту технологиялары

Андатпа. Жоғары техникалық-экономикалық тиімділікті және тау-кен жұмыстарының қауіпсіздігін арттыруды ескере отырып, көмір өнеркәсібінде қазбаларды бекітудің және тау сілемін тұрақтандырудың жоғары технологиялық ресурсын үнемдейтін әдістерін және белсенді құралдарын әзірлеу және тәжірибелік сынақтан өткізу өзекті болып табылады. Ұзын қабырға алдында өңдеу жұмыстарын жүргізу үшін контурға жақын тау жыныстарының кернеулі-деформациялық күйін басқару негізінде қолжетімді отандық технологиялар әзірленуде. Бұл шолу мыналарға мүмкіндік береді: көмір шахталарында анкерлік бекіткіш пен шайырлы бекітетін құрамдарды практикалық пайдалануды талдау; тау-кен қазбаларындағы пішіннің өзгеру үдерісінің параметрлерін зерттеу; анкерлік бекіту технологиясының тау-кен өндірісінің пайдалану сипаттамасына әсерін анықтау.

Түйінді сөздер: *тау жыныстары қысымының жоғарылау аймағы, технологиялық сызбалар, бекіткіш, анықтамалық қысым, анкерлік бекіткіш кедергісі, тау жынысы төбесінің жылжуы, тау-кен қазбалары, деформациялық процестерді зерттеу, бекіту параметрлері, көмір өндіру.*

Технологии крепления горных выработок на основе управления напряженно-деформированным состоянием

Аннотация. Разработка и опытно-промышленная апробация высокотехнологичных ресурсосберегающих способов и активных средств крепления выработок и стабилизации горного массива является в угольной отрасли до сих пор актуальной с учетом высокого технико-экономического эффекта и повышения безопасности горных работ. Для поддержания подготовительных выработок впереди лавы на основе управления напряженно-деформированным состоянием приконтурного массива горных пород разрабатываются доступные отечественные технологии. Проведенный обзор дает возможность провести: анализ практического использования анкерного крепления и смоляных закрепляющих составов в угольных шахтах; исследование параметров деформационных процессов в горных выработках; установление влияния технологии анкерного крепления на эксплуатационную характеристику горной выработки.

Ключевые слова: *зона проявления повышенного горного давления, технологические схемы, крепь, опорное давление, сопротивление анкерной крепи, смещения кровли выработки, горные выработки, изучение деформационных процессов, параметры крепления, добыча угля.*

Introduction

Underground mine workings of the mines of the Karaganda coal basin are in an unstable state (displacement of rocks of the roof, soil and sides) and are maintained with great labor intensity of work and material costs, since there are no justifications for the compliance of the supporting parameters with operating conditions in mining and geological, technical and production conditions. In order to make reasonable technological decisions to determine the parameters of the lining and its efficient operation, it becomes necessary to perform a geomechanical predictive assessment of the deformed state of the rocks of the enclosing rock mass around the workings. Accordingly, the introduction of technology and means, taking into account the stress-strain state of the host rocks, makes it possible to reduce material and labor costs and reasonably apply the parameters of mine workings support.

One of the current trends in the coal industry today is the development of high-tech resource-saving methods and active means of securing workings and stabilizing the rock mass with the achievement of a technical and economic effect and improving the safety of mining.

Underground mine workings of coal mines are the objects of research that are carried out and maintained in various mining and geological and mining technical operating conditions, including complicating factors such as: zones of increased and reference rock pressure, the presence of geological disturbances in various schemes for the development of mining operations, under- and layer processing.

The purpose of this article is to analyze the development of technology for maintaining development workings in front of the lava based on the management of the stress-strain state of the near-contour rock mass.

The use of developments in technologies for conducting mine workings, taking into account the stress-strain state of a coal-rock massif, to establish optimal supporting parameters depending on mining, geological and mining operating conditions, based on digital modeling of processes in host rocks around a mine working with the interaction of a rigid lining and a near-contour rock mass, is achieved with the successful application of methods and means of metal rods with a helical surface and rope-cable anchors of deep laying, installed in drilled holes in a given order in density, angle and length on fixing chemical compositions, in the zone of stress state (reference rock pressure ahead of the longwall) according to the criterion of rock strength for their fixation (weakened rocks, where inelastic deformations are manifested), which interact with each other and the host rocks, and, if necessary, with contour resin injection, creating a stable beam with a single-level and supporting system – with a two-level supporting (with attachment to stable roof rocks) of the enclosing array around the contour of the working.

When conducting an analysis of the practical use of anchoring and resin fixing compounds in coal mines; study of the parameters of deformation processes in mine workings; assessment of the technological parameters of the

use of rock bolts, depending on the geological and mining conditions of mine workings; study of the stress-strain state of the rock mass around the workings through analytical modeling; establishing the influence of anchor supporting technology on the operational characteristics of a mine working, methods and means of supporting and stabilizing the enclosing rock mass were developed, which will allow controlling geomechanical processes to reduce the intensity of the formation of delamination zones, fracturing and zones of discontinuity, weakened zones and reduce increased deformations of the coal-rock massif in the stope and around the development working, to avoid the formation of zones with excessive stress-strain state of the rock mass to increase stability and reduce the defectiveness of the rock mass.

Materials and research methods

During the study, the following methods were used: monitoring the stability of mine workings of the mines of the Karaganda coal basin with the determination of the patterns of manifestations of rock pressure depending on mining and geological factors and mining operating conditions, taking into account computer modeling of geomechanical processes in the enclosing coal-rock massif.

Results and discussion

The development of advanced technological solutions for the implementation of the technology of anchoring workings in front of the longwall and strengthening the rocks with resins to strengthen the disturbed (or weakened) rock mass to ensure the efficient and safe operation of coal mine links is of great practical importance and requires the implementation of appropriate types of work:

- development of technology and means of supporting, taking into account the geomechanical state of the massif and schemes for the development of mining operations;
- to form progressive technological solutions, to manufacture a pilot batch of means for contour strengthening of the rock mass and to monitor the technologies being introduced for supporting the contours of workings (testing pilot batches for various purposes);

Table 1

Characteristics of polymer ampoules

Кесте 1

Полимерлі ампулалардың сипаттамасы

Таблица 1

Характеристики полимерных ампул

Hard capsule type	Gel time, s	Hardening time, s
Fast	10-18	8-10
Medium	40-55	10-15
Slow	70-200	30-50

- carrying out pilot testing and implementation of the results of research to improve the technological schemes for working with rope and composite anchors in the mines of the Karaganda coal basin;
- to create progressive methods of supporting during workings in the zones of geological disturbances, zones of increased rock pressure (technological schemes), incl. with synthetic resins.

The study consists in substantiating the qualitative and quantitative parameters of mine workings contour support systems, taking into account the geomechanics of the coal-rock enclosing massif, based on the developed technological approaches to create safe conditions and increase

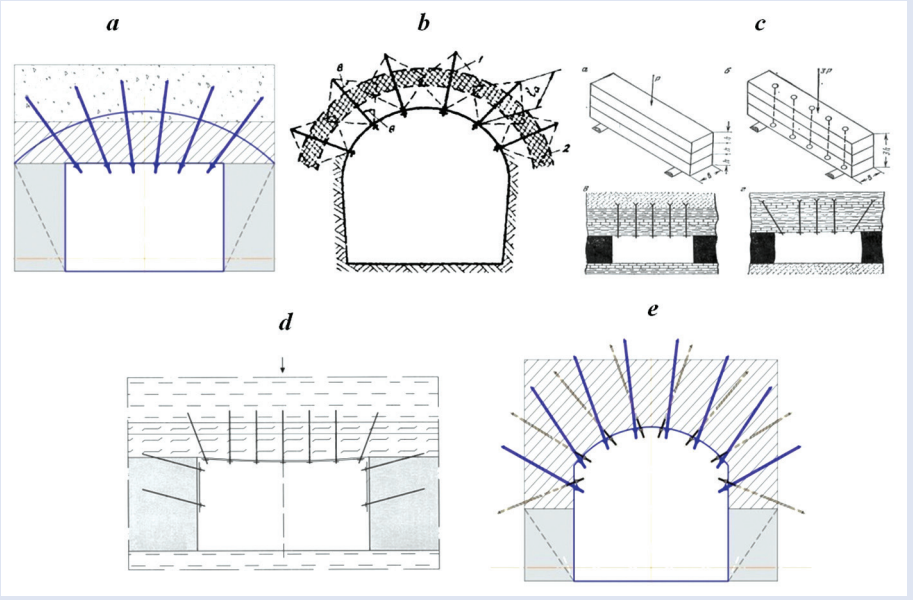

Figure 1. Theories used in the calculation justification of the parameters of the anchor lining.
Сурет 1. Анкерлік қаптаманың параметрлерін негіздеу есебінде қолданылатын теориялар.
Рис. 1. Теории, использованные при расчетном обосновании параметров анкерной крепи.

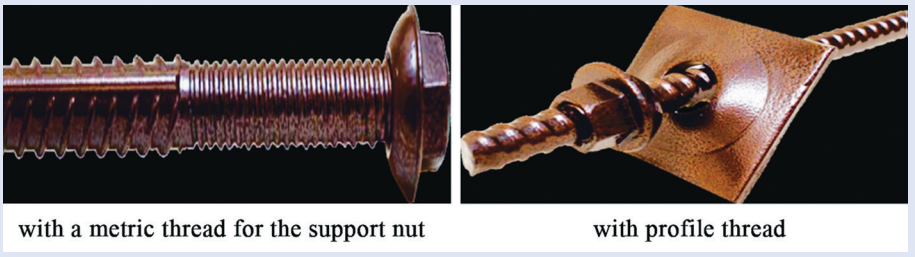

Figure 2. Rigid steel (metal) anchor.
Сурет 2. Қатты болат (металл) якорь.
Рис. 2. Жесткий стальной (металлический) анкер.

Figure 3. Fiberglass anchor with a solid rigid base plate.
Сурет 3. Қатты негіз пластинасы бар шыны талшықты якорь.
Рис. 3. Анкер из стеклопластика со сплошной жесткой опорной плитой.

labor efficiency in high-performance stopes and development faces; as well as the location of the contour support relative to the bedding of rock layers; determining the parameters of a single-level beam anchor supporting; the location of the contour supporting relative to the elements of the working during heaving of soil rocks; creation of a fixing contour beam above the working with the establishment of the influence of the strength of the host rocks on the magnitude of stresses and delaminations of the boundary rocks; in the study of the stress-strain state of the rock mass during the supporting of workings in the zone of support pressure of the stope in front of the longwall; in establishing the influence of technological factors on the conditions for maintaining the contours of mine workings: the angle of inclination of the contour anchors on the stress state of the rock mass.

In this regard, the scientific significance lies in:

- study of the stability of workings fixed with anchor bolting at the mine of the Karaganda coal basin with the determination of the parameters of deformation processes (according to the results of industrial observations);
- establishing patterns of development of the sizes of zones of development of deformations and stresses around the working from geological and technological parameters to the reference rock pressure in front of the lava (analytical modeling), with one- and two-level supporting.

According to the conducted research, the following points should be noted:

- the angle of inclination of the contour rope anchor for workings with a rectangular shape is recommended to be 75-77° at minimum normal stresses, when installed in the zone of influence of mining (cleaning) works in front of the lava;
- load-bearing anchor beam provides a reduction in stresses perpendicular to the layering of rocks with a single-level anchor lining by 10-15% and a smaller spacing on the sides of the working – by 20%; reduction of heaving of the working soil – by up to 5%;
- the integrity of the roof, reinforced with anchors 2.4 m long, is maintained at horizontal stresses up to 15-16 MPa, and at stresses of 16-19 MPa or more, the integrity of the roof is ensured by installing rope anchors; with the growth of vertical stresses, it is carried out by binding the near-contour massif of weak rocks with the overlying rocks using deep anchors, which leads to the suspension of the formed bearing beam of rocks to a stable massif and balancing the load on the working support;
- the influence of the strength of the host rocks on the magnitude of stresses and delaminations of contour rocks: 2.4 m for strong rocks (compressive strength 40-60 MPa); 2.6 m for rocks of medium strength (compressive strength 35-40 MPa); 2.8 m for low-strength rocks (compressive strength less than 35 MPa) and 3.8 m for unstable rocks;
- regularities of the influence of the anchor length, the depth of development and the thickness of an unstable layer (for example, mudstone) on the stability of a rectangular mine working.

As a result of the work described above, recommendations were given on the effective use of the technology of anchoring the workings during development workings in the zones of tectonic disturbances and smolyanization of the disturbed rock mass at the junctions and in the longwalls of the mining areas of the mines of the Karaganda coal basin.

There are five main theories (Figure 1) used in the calculation justification of the parameters of the anchor lining: suspension of the direct roof to stable rocks (*a*); formation of a load-bearing structure – an anchor bridge (*b*); compression of supporting rocks (*c*) – layered beam interaction; joint work of the support and the array (*d*) – with their equal strength; energy theory (*e*), based on the fact that a dangerous state occurs when the specific potential energy of shape change reaches the limit value [1].

The main types of anchor bolting can be divided according to the design of the anchor rod: metal locking; metal lockless (explosive); wooden; reinforced concrete; steel-mineral; steel polymer; plastic; basalt-plastic; friction; injection; self-drilling; rope.

Metal rigid anchor. Anchor is a rigid metal rod that is installed in the roof or side wall of a working and is used in combination with a full pour of resin (cement mortar) in a hole (borehole) or other appropriate substance to provide a reinforced roof and the sides of a working (Figure 2).

Fiberglass anchor – rod made of fiberglass materials and characterized by high tensile strength. Anchors are fastened in boreholes using polymer ampoules or polymer compounds (Figure 3).

A support spherical washer (support damping plate) is used in combination with an anchor and a hemisphere nut and helps to distribute the load, ensuring the correct location regardless of the angle of installation of the anchor, reducing erosion around the mouth of the anchor hole (Figure 4).

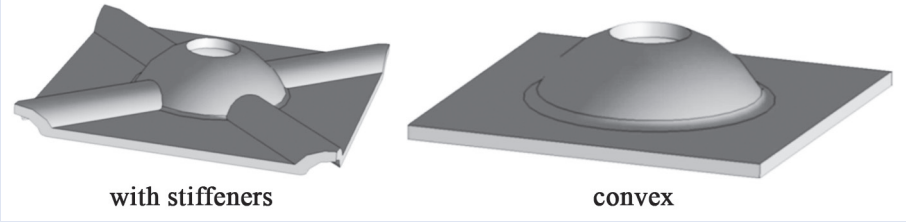

Figure 4. Steel spherical washer.
Сурет 4. Болат сфералық шайба.
Рис. 4. Стальная сферическая шайба.

Figure 5. Rope injection anchor.
Сурет 5. Арқанды бүрку анкері.
Рис. 5. Канатный инъекционный анкер.

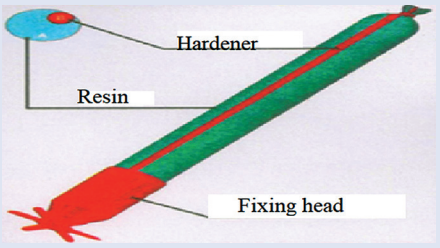

Figure 6. Polymeric or mineral anchor fixer in the form of ampoules.
Сурет 6. Ампулалар түріндегі полимерлі немесе минералды анкерлік бекіткіш.
Рис. 6. Полимерный или минеральный анкерный фиксатор в форме ампул.

Hemisphere nut – must be made of steel or fiberglass, hexagonal and the distance between the faces must be 36 m.

Strip anchor catch (strip) – metal strips with holes installed in the roof and sides of the workings, connecting the anchors in rows into a single jointly working system. In the structures of support-anchor supporting, the following are used: lightweight grabs – with an installation density of anchors in the roof of more than 1 piece/m^2; reinforced grabs – with an anchor density of less than 1 piece/m^2.

Rope anchor[1] is designed for fixing mine workings by deep anchoring of surrounding rocks (5-7 m and more). The rope anchor is fixed using a polymer composition or cement mortar along the entire length of the hole. To control the completeness of filling the hole with a fixing composition, a central air outlet tube was introduced into the anchor design.

Rope injection anchor. Designed for fixing unstable rocks at mates (Figure 5), mine workings by deep anchoring of surrounding rocks. The rope anchor is fixed using a polymer composition or cement mortar along the entire length of the hole. To control the completeness of filling the hole with a fixing composition, a central air outlet tube was introduced into the anchor design. The injection of the bonding composition into the borehole is stopped when resin appears from the air outlet tube [2].

Chemical resin is an encapsulated material used to create adhesion between the anchor and the side rocks of the roof and sides (soil) of the working. Capsules (Figure 6) should contain filled polyester resin and catalyst in separate compartments with a fragile shell [3-5].

The gel time and the hardening time of the chemical material after mixing the capsules into the hole for 20 seconds at a temperature of 20-30°C and must comply with Table 1.

PUR-cartridges (Figure 7) contain a fast-reacting polyurethane resin in a two-section plastic shell. The holes are drilled at the site of the PUR-cartridge use. The distance between the holes depends on the degree of the coal looseness or the environment and on the expected load. The cartridges are individually placed as deep as possible to the bottom of the hole. A tetrahedral wooden block is partially hammered into the hole and then screwed in until it stops using the rotary drill or the impact drill with an adapter.

To strengthen the coal massif in the development workings there are drilled holes in the side of the mine working at the intervals of 0.8-1.0 m in two rows; the holes in the bottom row are drilled at the distance of 0.8-1.0 m from the top in the chessboard pattern; the length of the holes is 2.0-2.2 m, the diameter of the hole is 43 mm; PUR cartridges are placed in the hole and sent to the bottom of the hole with a wooden bar; the length of the bar is 2.2-2.5 m, the cross-section of the bar is 30 × 30 mm, one end of the bar is beveled at the angle of 45°; the destruction and mixing of PUR-cartridges is performed by rotating the bar with an electric drill through an adapter within 10…15 s. The quality control of mounting a wooden anchor and the required number of PUR-cartridges per hole is controlled by the exit of the foamed composition from the mouth of the hole [6, 7].

Basalt plastic anchor. It is designed for supporting the sides of the workings (Figure 8), especially from the bottom side of the adjacent development workings for the long-wall face passage; it is not subject to corrosion.

Friction anchor. It is used for supporting massive unstable rocks in mines (Figure 9) with water being supplied to the internal cavity under high pressure (20 MPa) or by driving a metal spacer rod with the anchor wedging in the hole.

Resin products for stabilization of unstable rock massifs

Two-component polyurethane resin BlockPUR [2]. The technology of using the resin is presented in Figure 10: to stabilize an unstable and disturbed

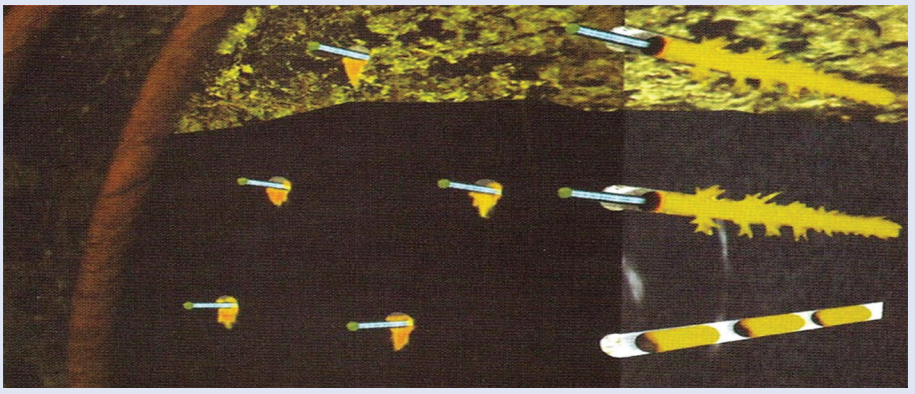

Figure 7. PUR cartridge supporting technology.
Сурет 7. PUR картриджді қолдау технологиясы.
Рис. 7. Технология крепления PUR картриджа.

[1]*Demin V.F., Zhurov V.V., Demina T.V. Geomechanics in rock fixing. – LAP LAMBERT Academic Publishing. – 2013. – 185 s. (in Russian)*

Figure 8. Basalt plastic anchor.
Сурет 8. Базальт пластикалық якорь.
Рис. 8. Анкер базальтопластиковый.

rock massif; to mount anchors with strengthening the surrounding massif; waterproofing rocks and various structures. The types of resin are as follows: BlockPUR C for dry breeds; BlockPUR B for wet rocks; BlockPUR VI for waterproofing.

The operational advantages include a quick response; excellent adhesion; high strength and elasticity; resistance to aggressive effects of acids, alkalis, brines and other organic solvents.

Organic mineral resins

Blockfil is a two-component phenol foaming resin, the technology of which use is presented in Figure 1.11,a. The scope and conditions of use are as follows: filling out dumps and domes; filling voids to prevent gas accumulation; construction of fire lintels; fire insulation; jumper sealing; gas isolation; stabilization of the destroyed mountain range.

The advantages of its use include the following: a high speed foaming reaction does not require erecting an airtight formwork; a high foaming coefficient allows filling significant volumes of voids with low material consumption; it is a non-combustible material.

Blocksil is a two-component organic mineral resin. The technology of applying the resin is presented in Figure 11,b: to stabilize a weak and severely disturbed rock massif; coal strengthening in tunnel faces and lavas in zones of mining and geological disturbances; anchoring with the foundationless (pile) supporting of equipment and various designs; filling various voids by water displacement.

The advantages of the use are as follows: quick response, excellent adhesion, high strength and elasticity, it does not foam and does not expand even when in contact with water, it is resistant to aggressive effects of acids, alkalis, brines and other organic matters.

Discussion

On the development of technological schemes, methods and means of working with supporting based on the establishment of regularities in the manifestations of the stress-strain state of the coal-rock mass in the host rocks in numerical modeling and full-scale experiments in mine conditions to ensure a stable system of interaction between the supporting and the host rocks of the rock mass around mine

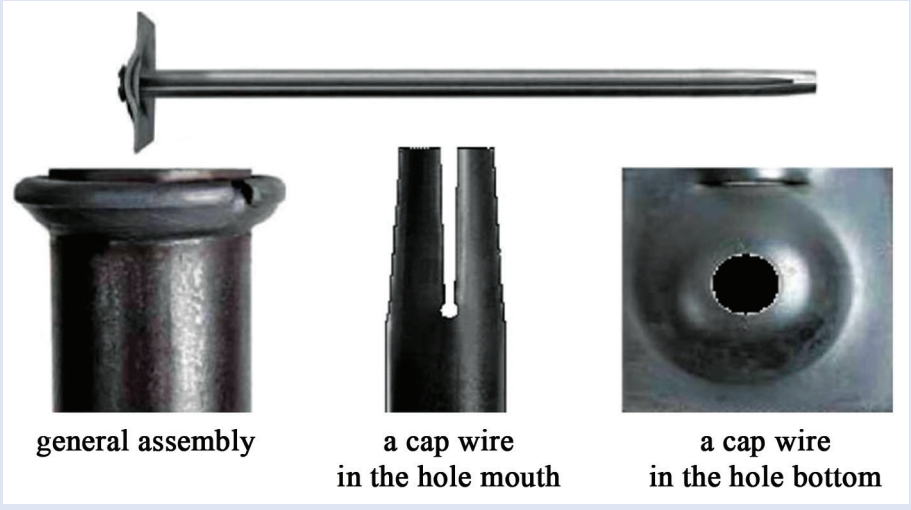

Figure 9. Friction anchor of the mine version.
Сурет 9. Шахта нұсқасының фрикционды анкері.
Рис. 9. Анкер фрикционный шахтного исполнения.

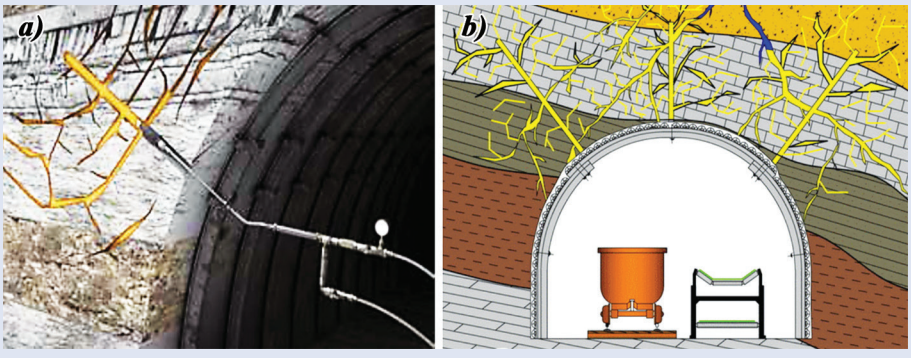

Figure 10. Technology of using two-component polyurethane resin in the sides (*a*) and the roof (*b*) of the working.
Сурет 10. Жұмыстың бүйірлерінде (*а*) және шатырында (*б*) екі компонентті полиуретанды шайырды қолдану технологиясы.
Рис. 10. Технология применения двухкомпонентной полиуретановой смолы в бортах (*а*) и своде (*б*) выработки.

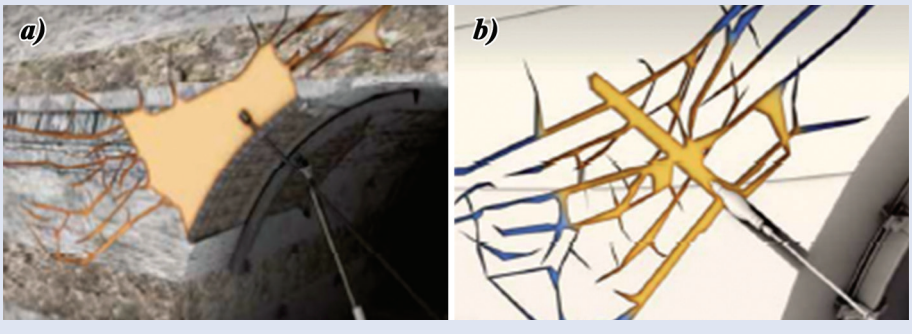

Figure 11. Technology of using two-component phenol foaming (*a*) and organic mineral (*b*) resins.
Сурет 11. Екі компонентті фенол көбіктендіргіш (*а*) және органикалық минералды (*б*) шайырларды қолдану технологиясы.
Рис. 11. Технология применения двухкомпонентных фенольных пенообразователей (*а*) и органоминеральных (*б*) смол.

Figure 12. The interaction of large and small fractions of rocks bonded with resin (*a*) and adhesion to the metal surfaces of arch metal and sheet profiled scrap (*b*); bonding of small and large fractions of the rock (*c*).
Сурет 12. Шайырмен (*a*) байланыстырылған тау жыныстарының үлкен және кіші фракцияларының өзара әрекеттесуі және арка металдың және қаңылтыр профильді сынықтың металл беттеріне адгезиясы (*b*); тау жыныстарының кіші және үлкен фракцияларының байланысы (*c*).
Рис. 12. Взаимодействие крупных и мелких фракций пород, связанных смолой (*a*) и адгезия к металлическим поверхностям арочного металла и листового профилированного лома (*b*); склеивание мелких и крупных фракций породы (*c*).

workings to maintain their contours, an assessment of the problem was made and the existing structures of contour laying systems when fixing mine workings supporting in coal (below) and ore mines [8, 9].

Despite significant increasing in the level of mechanization of production processes, the coal and mining industries remain the most labor-intense industries not always with a high level of safety of production processes performing.

According to the results of the industrial tests of the polyurethane resin «BlokpurS» at the mine of the Karaganda coal basin, it was found:

- at least not lower but higher strength of the bonded loose rock mass with the BlockPUR C resin with its lower consumption compared to the Bevedol-Bevedan polyurethane resin;
- excellent interaction between adjacent resin injections through perforated tubes from the drift;
- there is good adhesion to the metal surfaces of the arched metal and sheet profiled tightening;
- good bonding of fine and coarse fractions of the rock is achieved, and resin penetration is achieved in small cracks (0.15-0.2 mm in size), foaming and hardening in gaps and voids (Figure 12).

Conclusion

The industrial tests of the BlockPUR S polyurethane resin at the Kazakhstanskaya mine in the conditions of the 324D6-2-B long wall face passed with a positive assessment of using the resin for fixing damaged, loosened rocks.

The pilot tests carried out allowed adapting and applying the developed technological solutions when using the BlockPUR S two-component polyurethane resin.

It should be noted that the development of rock pressure resulting from the interaction of host rocks with mine workings is decisively influenced by geological, mining and technological factors.

The deformed state of the massifs is a consequence of the interaction of stress fields and the properties of the massif (mostly physical and mechanical). The geomechanical conditions of supporting mining workings in the basin at great depths are characterized by increased complexity due to low strength of the rocks enclosing the coal seams, especially soils that already at low concentrations of rock pressure are prone to intense heaving.

This article presents the results of scientific and applied research on the production processes of the technology for conducting preparatory work in complicated mining and technical conditions for mining coal seams; the development of methods for controlling geomechanical processes during mining operations at the deep levels of coal mines; monitoring of implemented technologies for supporting the contours of mine workings.

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Авторлар туралы мәліметтер:
Жұмабекова А., PhD, «Әбілқас Сағынов атындағы Қарағанды техникалық университетінің» Коммерциялық емес акционерлік қоғамы, «Пайдалы қазбалар кен орындарын игеру» кафедрасының аға оқытушысы (Қарағанды қ., Қазақстан)
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This research has been/was/is funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant No. AP13268841)