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Satbayev University

ХАБАРЛАРЫ

ИЗВЕСТИЯ

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TOP-DOWN CUT-AND-FILL MINING METHOD AT THE PERVOMAYSKIY DEPOSIT OF THE DONSKOY MINING AND BENEFICIATION PLANT

Abstract. Based on the analysis of the world experience in the application of filling methods for ore extraction and laboratory studies, a technology has been developed for preparation of filling mixtures by a mill-mixing method with the possibility of operational transformation of the process flow diagram depending on the type of binding material (cement and cement-slag) and filling material (tailings, screenings, rock or sand). A backfill plant has been built, and pilot testing of the top-down cut-and-fill mining system of chrome ores has been started at the Pervomayskiy deposit under the protection of artificial ceiling, created in the upper layer of each sub-level.

In the course of pilot tests, of the top-down cut-and-fill mining system with hardening mixtures and the complication of mining conditions showed the perspectivity of its use for excavation of reserves under artificial overburden as thick and medium thickness ore bodies of lower horizons.

With a descending layered mining system, stopes and layered workings are filled with hardening mixtures with the formation of a bearing layer and a layer of reduced strength. The normative strength of an artificial mass in a layer of reduced strength (topping layer) is determined by the stability escarpments, and with their height up to 3.5 m, it must be at least 0.7 MPa.

The normative strength of the backfill bearing layer according to the condition of stability of the horizontal outcrop (development of penetrations on the underlying layer) should be achieved at a 90-day hardening (4.0 MPa without reinforcement and 3.0÷3.5 MPa with reinforcement).

The composition of the filling mixture must ensure the standard strength of the artificial mass within the specified hardening time and be transportable through pipes due to pressure drop.

Key words: Chromium ores, Cut-and-fill mining method, Backfill plant, Artificial ceiling, Dilution.

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ПЕРВОМАЙ КЕН ОРНЫНДА ДОН ТАУ-КЕН БАЙЫТУ КОМБИНАТЫН ТӨМЕН ҚАБАТТЫ ИГЕРУ ЖҮЙЕСІ

Аннотация. Кен өндіру кезінде толтырмалау әдістерін қолданудың әлемдік тәжірибесін талдау негізінде тұтқыр (цемент немесе цемент-қож) және толтырғыш (тау жыныстары, қалдықтар, еленді немесе құм) типіне және талап етілетін өнімділікке байланысты технологиялық процестің сұлбасын жедел трансформациялау мүмкіндігімен толтырмалау қоспаларды дайындаудың диірмен-араластыру технологиясы әзірленді.

Первомай кенорнында әр төменгі деңгейдің жоғарғы қабатында жасалған жасанды төбені қорғауымен қайта толтыру қондырғысы салынды және хром кендерін қазу жүйесіне тәжірибелік-өнеркәсіптік сынақтар жүргізілді. Тәжірибелік-өнеркәсіптік сынақтар барысында төменгі қабатты игеру және қатты қоспалармен өңделген кеннен алынған кеңістікті тығындап қазу жүйесі және қазымдаудың тау-кен техникалық жағдайларын қиындата отырып, оны төменгі деңгейжиектегі кен денелерінің қуатты және орташа қуаты ретінде жасанды қабаттасу астындағы қорларды алу үшін келешекте қолдануға болатынын көрсетті.

Төмен қабатты игеру жүйесінде тазарту енбелері мен қабатты қазбалар тірек қабаты мен беріктігі төмен қабатты қалыптастыра отырып, қатайтатын

қоспалармен толтырылады. Төмен беріктік қабатындағы жасанды массивтің нормативтік беріктігі (толтыру қабаты) тік ашылымның тұрақтылығымен анықталады және олардың биіктігі 3,5 м-ге дейін болса, ол кемінде 0,7 МПа болуы керек. Көлденең ашылымның орнықтылығы шарты бойынша төсемнің негізгі қабатының нормативтік беріктігіне (төменгі қабаттағы енбелерді пысықтау) қатаюдың 90-тәуліктік мерзімінде (арматуралаусыз 4,0 МПа, арматуралаумен 3,0÷3,5 МПа) қол жеткізілуі тиіс.

Толтырғыш қоспаның құрамы қатаюдың белгіленген мерзімінде жасанды массивтің нормативтік беріктігін қамтамасыз етуі және қысымның төмендеуі есебінен құбырлар арқылы тасымалдануы керек.

Түйін сөздер: хром кендері, төмен қабаттап қазу жүйесі, қазынды кеңістікті толтырмалау, жасанды төбе, араластырғыш.

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НИСХОДЯЩАЯ СЛОЕВАЯ СИСТЕМА РАЗРАБОТКИ НА ПЕРВОМАЙСКОМ МЕСТОРОЖДЕНИИ ДОНСКОГО ГОКа

Аннотация. На основе анализа мирового опыта применения методов закладки при добыче руды разработана мельнично-смесительная технология приготовления закладочных смесей с возможностью оперативного трансформирования схемы технологического процесса в зависимости от типа вяжущего (цементное или цементно-шлаковое) и заполнителя (порода, хвосты, отсев или песок) и требуемой производительности. На Первомайском месторождении под защитой искусственной потолочины, созданного в верхнем слое каждого подуровня, построена установка обратной засыпки и начаты опытно-промышленные испытания системы отработки хромовых руд.

В ходе опытно-промышленных испытаний нисходящая слоевая система разработки и закладки выработанного пространства твердеющими смесями и усложнением горнотехнических условий отработки показала перспективность его применения для выемки запасов под искусственным

перекрытием как мощных и средней мощности рудных тел нижних горизонтов. При нисходящей слоевой системе разработки очистные заходки и слоевые выработки закладывают твердеющими смесями с формированием несущего слоя и слоя пониженной прочности.

Нормативная прочность искусственного массива в слое пониженной прочности (слой доливки) определяется устойчивостью вертикальных обнажений, и при их высоте до 3,5 м она должна быть не менее 0,7 МПа.

Нормативная прочность несущего слоя закладки по условию устойчивости горизонтального обнажения (отработка заходок на нижележащем слое) должна быть достигнута в 90-суточном возрасте твердения (4,0 МПа без армировки, 3,0÷3,5 МПа с армировкой). Состав закладочной смеси должен обеспечить нормативную прочность искусственного массива в заданные сроки твердения и быть транспортабельным по трубам за счет перепада давления.

Ключевые слова: хромовые руды, нисходящая слоевая система разработки, закладка выработанного пространства, искусственная потолочина, смеситель.

Introduction. The world resources of chromium ore are estimated at 15 billion tons. South Africa takes the first place in terms of chromite reserves (76% of explored reserves), Kazakhstan takes the second place (9% of explored reserves). However, in terms of quality, Kazakh South-Kempirsay deposits are unrivaled throughout the world. The mass fraction of the extracted chromium oxide is 50-52% (Til, et al., 2013:9). The '10th anniversary of Kazakhstan independence' mine is the largest in the world in terms of extraction of chromium ores and uses the method of ore and host rock caving.

Research Material and methods. The most important disadvantages of the method are the large loss and dilution of the ore (20-25%). The decrease of dilution even by 10-15 % allows decreasing costs for ore beneficiation or even avoiding this process.

Caving methods can't be used for mining of ore reserves in protective and safety pillars for important infrastructure and water ways, and don't allow undermining of upper-laying ore bodies.

When the mining depth increases, the costs for driving, lining and maintenance of drifts, also increase (it requires reconstruction of 100 running meters of drifts for each 100 thousand tons of mined ore).

In order to solve this problem, the Development strategy of the Donskoy mining and beneficiation plant until 2030 suggests adopting a mining method with backfilling of mined-out space during development of the southern part of the Millionnoye deposit, and the northern part of the Almaz-Zhimchuzhina

deposit, on a second-priority basis, by the '10th anniversary of Kazakhstan independence' mine. In the future, approximately up to 25% of the total volume of available ore will be mined using this method.

The analysis of the world experience in application of mining method with backfilling of mined-out space during development of deposits with complex ground conditions with unstable ores and host rock was performed (Bronnikova,1987:136).

It was found out that the combined mining method is more widely used in similar conditions. First, an artificial ceiling is created, and under its protection, the ore reserves are mined by the chamber mining method with backfilling of the mined-out space. This method is used for formation of relieving zones for relieving of the massif of the increased stress, during mining of rich ores in the emergency (dangerous) areas, and when working with water-bearing levels (Kump et al., 1990:5).

The top-down cut-and-fill mining method with backfilling of the mined-out space and engagement of mobile equipment is widely used for development of the Orlovskiy pyrite-complex ore deposit (since 1987). (Ananin, et al, 2002a:3). Currently, this mining method with production capacity of 1 million tons of ore per year is effectively used at the Orlovskaya and the Artemyevskaya mines of the 'Vostoktsvetmet' Llc. (Kazakhstan) (Ananin, et al 2002b:5).

For the development of mining technology with backfilling of the mined-out space, a pilot site was assigned at the Pervomayskiy deposit: level +240 m +160 m.

The affiliate of RSE 'NE CPMRM RK' 'VNIItsvetmet' was the general designer. The Institute developed the detailed project for mining of the Pervomayskiy deposit with the capacity of 300 thousand tons of ore per year.

Stoping technology. The top-down cut-and-fill mining method with backfilling of the mined-out space under the protection of artificial ceiling was selected as a priority method (see Figure 1).

Preparation of the block includes driving of strikes, access ramp, entries to each layer, orepass and ventilation-filling raise (*Aimbetov,* et al, 2018: 5).

The reserves of the block are mined top-down by layers. Ore excavation in the layers is carried out by stopes with section of 4×4 m. These stopes have an inclination of 2-3° (by 1-2° more than the angle of repose (spreading) of the mixture) for completeness of backfilling of the mined-out space (*Makarov,* et al, 2017: 4).

Stoping may be carried out simultaneously at two or three sub-levels. At the same time, the vertical distance between simultaneously mined layers in the neighboring sub-levels should be at least 20 m. (Krupnik, et al, 2010:7).

The work at each sub-level starts with formation of the artificial ceiling by mining and filling of the upper layer. If the ore is highly unstable, stopes are

mined using outstrip bolting (forepoling) and arch supports. Reinforcement of ceiling is performed using reinforcing bars and mesh wire (see Figure 2).

Expansion of the work in the layer begins with driving from the entry to the layer of stope drift with its location:

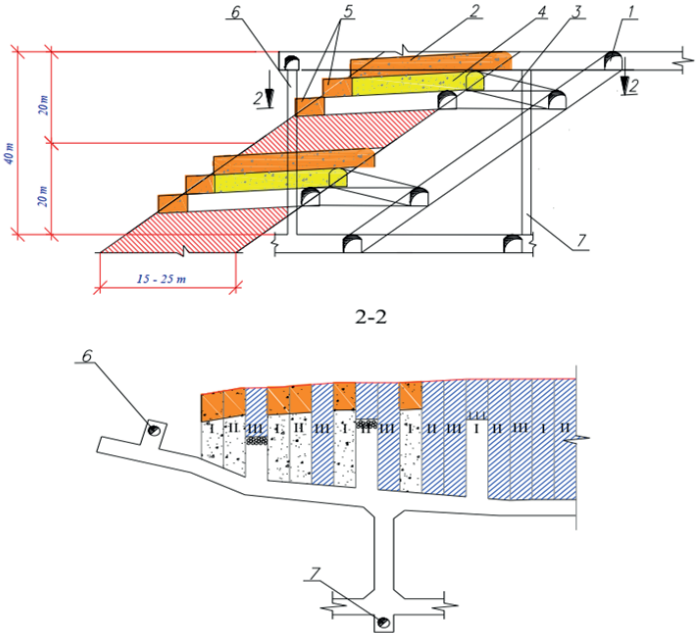
- cross-strike with horizontal thickness of the ore body of up to 15 m;
- along the strike from the hanging or laying wall with horizontal thickness of the ore body of 15-30 m;
- along the strike in the middle of the ore body, if its thickness is more than 30 m.

Due to such location of the stope drift, the optimal length of the stope is achieved and a number of two-sided intersections is reduced. (*Kashnikov,* et al, 2010:7).

If two-sided allocation of stopes in the stope drift takes place, then their axis should be shifted by half the width of the drift.

It is recommended to set the length of the stope taking into account the following parameters:

- amount of time when the stope was kept without backfilling (the longer it was kept, the less stable the roof becomes);
- the necessity for placement of the intermediate fill walls;
- providing the necessary extraction front (number of simultaneously mined stopes in the block) (Grigor'ev, et al, 2013:13).



1 - access ramp; 2 - ceiling (concrete reinforced with arches of special profile); 3 - access point to the layer; 4 - mined-out and backfilled stope; 5 - ceiling along the hanging wall of the ore body; 6 - ventilation and manway rise; 7 - orepass

Figure 1- The top-down cut-and-fill mining method with backfilling of the mined-out space under the protection of artificial ceiling

Figure 2- Reinforcement of the artificial ceiling

Stopes in the layer are mined in three turns or by side cutting (side slicing).

In case of mining in three turns, ore pillars should be left between face cuts of the first turn. Face cuts of the second turn are adjacent to the filling mass from one side and to the ore mass from another side. The face cuts of the third turn are excavated between backfilled face cuts.

An 8m ore mass, filled or ore-filled mass should be left between simultaneously mined stopes. At the same time, backfill strength should be at least 0.7 MPa.

When the stope is mined by side cutting, a hard ore mass is left on one side of the mined stope, which has a positive effect on its stability.

The stopes at the layers adjacent in terms of height are recommended to be placed in parallel to each other with a shift by half a section.

Stopes are backfilled with consolidating mixtures with formation of the base layer and the layer of reduced strength (Sakimov, et al, 2018: 10).

Characteristic strength of the base layer is determined by a width of stope, its thickness, presence of stratification (cleavage) and reinforcement, and also the sequence of stopes mining in the underlayer. If the stope has a 4 m width and thickness of the base layer is 1.5 m, at the time of undermining the backfill strength should be at least 4 MPa, if the layer is not reinforced, and 3.5 MPa, if the layer is reinforced.

The backfill strength of the artificial massif in the layer of reduced strength (filling-up layer) is determined by stability of stope's walls (escarpments). If the stope has the height of 3.5 to 6 m, then the backfill strength should be from 0.7 to 1.0 MPa, correspondingly.

According to calculations, the loss and dilution of the ore should not exceed 5 %.

Result and discussion. Backfilling of the mined-out space. The conception of the backfilling operations development at the Donskoy mining and beneficiation plant includes not only the use of advanced technologies for backfilling

operations, but also the use of efficient methods for utilization of production waste and solving of environmental issues (Doudkin, et al, 2019:7).

Mining waste and beneficiation production waste were tested for the use as inert aggregate. The cement-slag and serpentinite based binding materials were developed. The optimal compositions for filling mixtures were determined (see Table 1).

Table 1- Process chart for compositions of the filling mixture.

Purpose	**Components consumption, kg/m³**				
	Cement	**Water**	**Sand**	**Screenings**	**Tailings**
Base layer, strength at 90-days of maturing R=3.5-4.0 MPa	250	420	450	900	-
	250	420	1000	500	-
	250	400	450	-	1000
Topping-up, strength at 7-days R = 0.7-1.0 MPa	130	410	470	980	-
	150	420	1000	500	-
	130	410	500	-	1050

A mill-mixing technology for preparation of filling mixtures with the possibility of operational transformation of the process flowsheet, depending on the type of binding material (cement or cement-slag), and filling material (rock, tailings, screenings, or sand), and the required efficiency, was developed (see Figure 3).

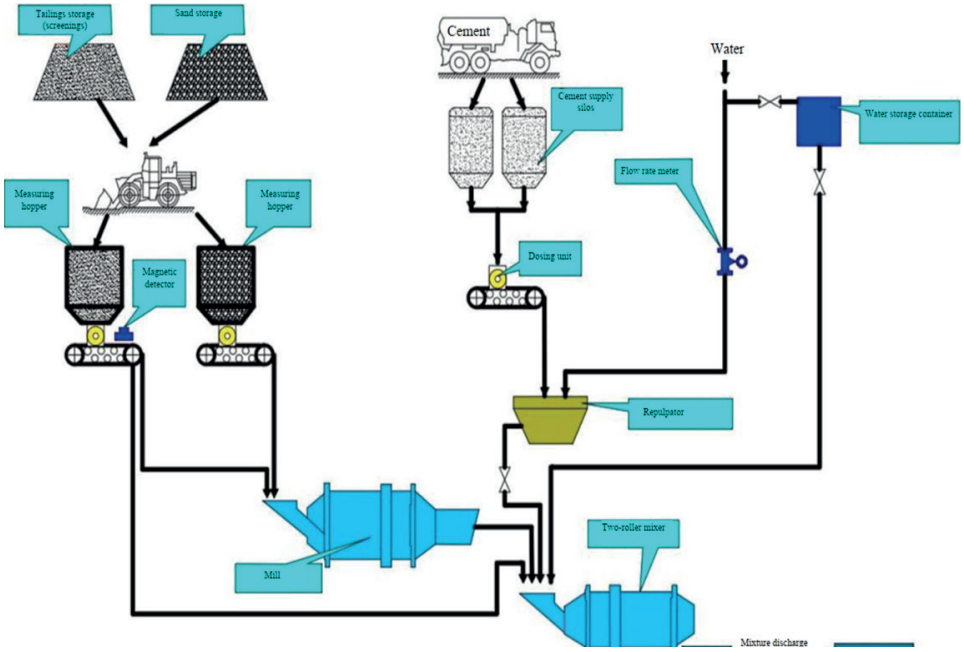


Figure 3. Process flowsheet for the milling-mixing section of the concrete backfilling plant.

Concrete backfilling plant with capacity of 19 m^3/hour was built at the mine site of the 'Vspomogatelniy' shaft according to the project of VNIItsvetmet Institute and put into operation in 2017 (see Figure 4, 5, 6).

Figure 4. Concrete backfilling plant of the Pervomayskiy deposit

Figure 5. The Mill МШР 2.7×2.1

Figure 6. The Mixer SU-1

The main requirement for backfilling massif, as a means of controlling rock pressure, is to maintain stability when it is exposed and to ensure that the elements of mining systems are maintained in a stable state.

The stability of backfill in outcrops is ensured by its mechanical strength, which is able to withstand the effects of static and dynamic loads.

As the main characteristic of the backfill strength, the uniaxial compressive strength is taken, determined when testing specimens according to GOST 10180-2012.

The mined-out space is laid with hardening mixtures of various compositions with the formation of an artificial filling mass of different strength in height:

- carrier layer - part of the backfill mass, for which the standard strength is established according to the condition of stability of horizontal exposures;

- layer of reduced strength (additional filling) - part of the filling mass above the bearing layer, for which the standard strength is set according to the condition of stability of vertical outcrops.

The carrier layer is created with a thickness of 1.5 m. At a spreading angle of the filling mixture of 2-3, a penetration height of 4 m and a length of 30 m, the volume of the topping layer and the carrier layer are approximately equal.

The normative strength of an artificial mass in a layer of reduced strength (topping layer) is determined by the stability of the vertical outcrop and, with its height up to 2.5 m, it should be at least 0.4 MPa, and the average weighted by the height of the entry (taking into account the presence of a carrier layer in the outcrop) - 0.7 MPa. To ensure the front of cleaning work on the layer, such strength must be achieved within 14 days of hardening.

The normative strength of the backfill bearing layer with a thickness of 1.5 m according to the condition of stability of a horizontal outcrop with a span of up to 4 m (working out penetrations on the underlying layer) should be achieved at a 90-day hardening age with its reinforcement of 3.5÷4.0 MPa.

Conclusion. 1. The use the top-down cut-and-fill mining method with backfilling of the mined-out space during mining of rich highly unstable chromium ores will ensure the protection of water and critical structures with minimal losses and dilution of ore.

The top-down cut-and-fill mining system with hardening mixtures and the complication of mining conditions showed the perspectivity of its use for excavation of reserves under artificial overburden as thick and medium thickness ore bodies of lower horizons.

With a descending layered mining system, stopes and layered workings are filled with hardening mixtures with the formation of a bearing layer and a layer of reduced strength.

2. The most important element of the developed technology is the artificial

ceiling, which is created by working off the first (entry) layer by side cutting (side slicing) in to each. Stopes are mined using arched metal supports. To a height of 1.5 m stopes are performed using reinforcing bars and mesh wire and are backfilled with consolidating mixtures of increased strength.

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