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APPLICATION OF CHEMICAL ADDITIVES FOR WET SHOTCRETE PROCESS IN UNDERGROUND MINING

Abstract. The practice analysis results to use the shotcrete supports in the underground mines of Kazakhmys Corporation LLP have concluded that the 28 day-strength of concrete cube should be more 30 MPa. It should not have the breaks, cracks, blowholes and other defects. Plasticizers should be introduced into the concrete mix to meet the requirements for strength, flowability and setting time. Some disadvantages of the currently used material and method of its application have been determined. They have included the aggregates with fines which caused the excess consumption of cement and the drying of the washed aggregates to the required moisture content. The pilot tests of the sprayed concrete mix have been performed with using the Normet chemical additives to avoid disadvantages and to introduce the advanced technological solutions for the mining operations at Kazakhmys Corporation LLP.

Key words: *the underground mining, modes of occurence, shotcrete, strength class, compression, bending, the pilot tests, supports, plasticizer, the chemical additives, concrete mix, a setting accelerator.*

Жерасты кеніші жағдайында дымқыл әдіспен торкреттеу үшін химиялық қоспаларды қолдану

Андатпа. «Қазақмыс Корпорациясы» ЖШС жерасты кеніштері жағдайында торкрет-бетон бекіткіштерін пайдалану тәжірибесін талдау нәтижелері бойынша 28 күндік жастағы бетон тастың беріктігі 30 МПа-дан төмен болмауы, жарықтар, жарықтар, раковиналар және басқа да бұзушылықтар болмауы тиіс деген қорытынды жасауға болады. Беріктік, ұтқырлық және орнату мерзімі бойынша талаптарды қамтамасыз ету үшін пластификаторлар бетон қоспасына енгізіледі. Қазіргі уақытта қолданылатын материалдың бірқатар кемшіліктері және оны қолдану әдісі анықталды, соның ішінде толтырғыштарды тек ұсақ фракциялармен қолдану қажеттілігі, бұл цементтің көп шығынын тудырады; жуылған толтырғыштарды қажетті ылғалдылыққа дейін кептіру қажеттілігі. Кемшіліктерді жою, сондай-ақ тау-кен жұмыстарын жүргізу кезінде озық технологиялық шешімдерді енгізу мақсатында «Қазақмыс Корпорациясы» ЖШС кәсіпорнында normet өндірісінің химиялық қоспаларын қолдана отырып, бетон қоспасын шашуға тәжірибелік-өнеркәсіптік сынақтар жүргізілді.

Түйінді сөздер: *жерасты кеніші, пайда болу жағдайлары, бүріккіш бетон, беріктік класы, сығымдау, иілу, тәжірибелік сынақтар, бекіту, пластификатор, химиялық қоспалар, бетон қоспасы, қату үдеткіш.*

Применение химических добавок для торкретирования мокрым способом в условиях подземного рудника

Аннотация. По результатам анализа практики использования торкрет-бетонных крепей в условиях подземных рудников ТОО «Корпорация Казахмыс» можно сделать вывод, что прочность бетонного камня в 28-дневном возрасте должна быть не ниже 30 МПа, не иметь разрывов, трещин, раковин и других нарушений. Для обеспечения требований по прочности, подвижности и сроку схватывания в бетонную смесь вводятся пластификаторы. Выявлен ряд недостатков ныне применяемого материала и способа его нанесения, в том числе необходимость применения заполнителей лишь с мелкими фракциями, что вызывает большой перерасход цемента; необходимость просушки промытых заполнителей до требуемой влажности. В целях устранения недостатков, а также внедрения передовых технологических решений при ведении горных работ на предприятии ТОО «Корпорация Казахмыс» проведены опытно-промышленные испытания набрызг-бетонной смеси с применением химических добавок производства Normet.

Ключевые слова: *подземный рудник, условия залегания, торкрет-бетон, класс прочности, сжатие, изгиб, опытно-промышленные испытания, крепление, пластификатор, химические добавки, бетонная смесь, ускоритель схватывания.*

Description of the research object

The physical and mechanical properties of the ore-hosting rocks at the Zhomart underground mine have been characterized with the variable parameters. Their variability has been caused by the modes of occurence, anisotropy of the material composition, structure, texture and secondary changes. The fine-medium-grained sandstones, Raymond and intraformational conglomerates, gritstones, silty rocks and sandstones have been found in the ore-hosted strata of the open-cast. The ore deposit has been characterized as the medium-hard and hard strength coefficient *f* – from 6.1 to 13.3, and an average value – 8.9. Density of the copper ores was 2.71 t/m^3. The complex ores had the density of 2.8 t/m^3. The natural moisture content of copper ores in solid was 0.49% and 0.30% for complex ones. The porosity was 3.39% and 4.15%, respectively.

Generally, the mean-stable rocks have been found up to depth of 550 m. The depth interval of 550-860 m has contained the mean-stable, stable and very stable with the rare layers of unstable rocks. By the engineering and geological zoning, the central part of the occurence (4-I) has located in the zone of the mean-stable (60%) and stable (10%) rocks. As a rule, the side walls of the occurrence had the unstable rocks, and they have occupied about 30% of the area[1].

Theoretical treatment

The combined support used in the underground mine was a construction, i.e. shotcrete combined with the anchoring support. The main load-bearing

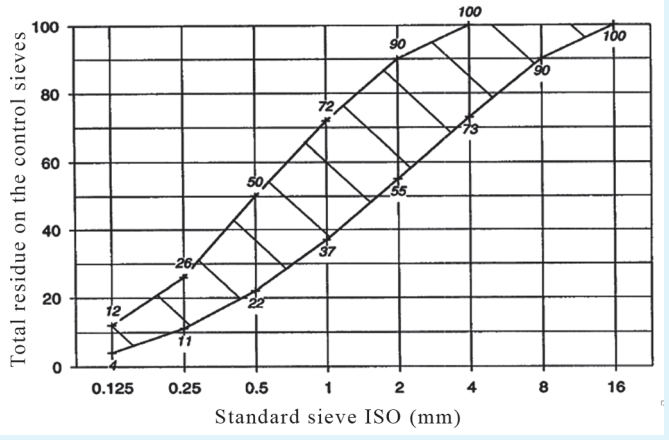

Figure 1. The grain-size composition of aggregates for shotcrete.
Сурет 1. Бүріккіш бетонға арналған толтырғыштың гранулометриялық құрамы.
Рис. 1. Гранулометрический состав заполнителя для торкрет-бетона.

[1]*Kazakhmys Corporation LLP. Instruction on arched support in mine workings at the Zhomart mine. – 2020 (in Russian)*

element was the rock layers strengthen by anchors as a whole. The shotcrete, protecting the rocks from weathering, has helped to maintain the parameters of the anchoring support. At the Zhomart mine, the compressive strength classes have been determined for shotcrete: B22.5; B25; B30; B35; B40, and bending tension: Bt1.6; Bt2; Bt2.4; Bt2.8; Bt 3.2; Btb 3.6 and Btb 4.0. The anchoring strength of shotcrete with the rock surface has met the requirements. The minimum values of the anchoring strength of shotcrete with the concrete and rock surfaces have been described in Table 1.

The water-cement ratio of the shotcrete: concrete mix with using the wet shotcrete process should be not more than 0.55, and 0.27-0.35 for the dry shotcrete process. The water-cement ratio in the wet shotcrete process has been adjusted with plasticizers, and could be reduced to 0.4. In this case, the concrete flowability for workability had to be complied with grade P4, and had an output cone slump of 18-20 cm or flow of 50-55 cm in compliance[2]. The temperature of the applied shotcrete mix components has been not less than 5°C. The cement brands have been selected on the basis of the required compressive strength class of shotcrete as specified in Table 2.

In order to obtain shotcrete, the basic materials have been used as follows: binders, aggregates, additives, water, and fiber if required. The Portland and slag cement[3] binders have been used under GOST 10178-85.

Subject of research

The aggregates have been applied for shotcrete such as a natural sand and gravel mix (e.g., ballast from the Kyzyl-Zhar occurrence)[4, 5] and sand under the GOST 8736 and GOST 9757. The characteristics of the natural sand and gravel mix have been described as follows. The gradation factor should be not less 2.5. A special

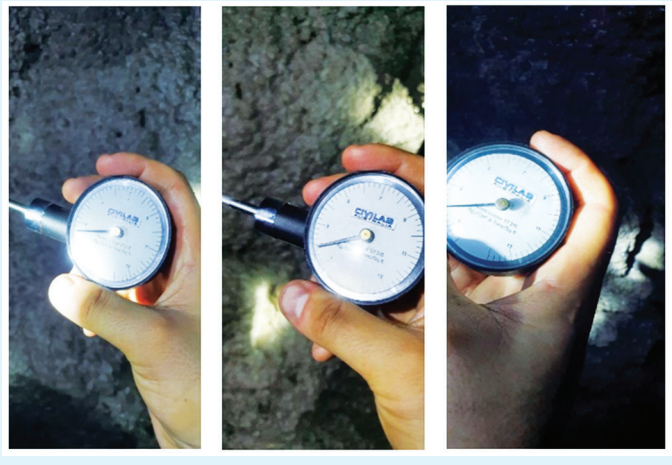

Figure 2. Data of the Civil Penetration after 60 min after spraying.
Сурет 2. 60 минут бүркуден кейін Азаматтық ену құрылғысының деректері.
Рис. 2. Данные с устройства Civil Penetration через 60 минут после набрызга.

Table 1

The anchoring strength of shotcrete

Кесте 1

Кесетін бетонның беріктігі

Таблица 1

Прочность сцепления торкрет-бетона

Type of sprayed surface	Minimum strength, MPa
Concrete	1.0
Rock	0.1

Table 2

Selection of the cement brand based on the required class of shotcrete

Кесте 2

Бүріккіш бетонның қажетті класына байланысты цемент маркасын таңдау

Таблица 2

Подбор марки цемента в зависимости от требуемого класса торкрет-бетона

Class of shotcrete	The required cement brand	Acceptable value
B22,5	400	500
B25	400	500
B30	400	500
B35	500	600
B40	500	600

experimental justification should be used for the sand less 2.5. The relative humidity should be up to 7%. A content of the dusty, silty and clay particles should be no more 2% by weight. The content of the clay lumps should be up to 0.3%. The grain fraction should be less 0.14 mm up to 10%. The maximum fraction content (more than 8 mm) should be less 10%. The particles more than 8 mm and clay lumps have been prevented during the screening, storage and processing of the aggregates. The grain-size composition of aggregates has been illustrated in Figure 1.

Plasticizers have been added into the concrete mix to meet the requirements for strength, flowability and setting time. Plasticizers had to comply with the requirements of their technical specifications and had the hygienic certificates.The shotcrete support should meet the requirements as follows. The layer thickness of the support should correspond to the design. The 28 day – strength of concrete cube should be more 30 MPa. It should not have the breaks, cracks, blowholes and other defects. It should be strong anchored with surface of the workings.The disadvantages of the used material and method of its application have been defined as follows. The aggregates with fines could cause the excess consumption of cement compared to the standard concrete. The dusting has been generated

[2]*GOST 10181-2000 «Concrete mixtures. Methods of testing» (in Russian)*
[3]*GOST 10178-85 «Portland cement and portland blastfurnace slag cement. Specifications» (in Russian)*
[4]*GOST 8736-93 «Sand for construction works. Specifications» (in Russian)*
[5]*GOST 9757-90 «Artificial porous gravel, crushed stone and sand. Specifications» (in Russian)*

Table 3

Selection criteria of concrete composition №MV8/9/22

Кесте 3

Бетон құрамын таңдау картасы №MV8/9/22

Таблица 3

Карта подбора состава бетона №MV8/9/22

Reference data	
Classification and nomenclature of concrete parameters (GOST 25192)	B22,5 F200 W4 P5
Concrete scope	For concreting of mine support with using the wet shotcrete process
The design properties of concrete and concrete mix:	
The compressive strength class of concrete	B22,5
The compressive strength of cubes after 28 days (with a coefficient of variation – 13.5%)	Not less 30MPa
Frost resistance grade of concrete	F200
Water resistance grade of concrete	W4
Workability of concrete mix grade	P5
Concrete pouring process into formwork	The spraying under pressure
Concrete curing conditions in structures	Natural +20
Characteristics of concrete mix components	
Cement (C) under GOST 10178	Portland cement
Type, variety, grade	PC 500 DO
Supplier plant	SemeiCement LLP
Cement activity (not less)	47 MPa
True density	3.1g/cm^3
Normal density	25.8%
Setting time: start/end	145 min/220 min
Screening	natural
Supplier of open cast	
Sand under GOST 8736	–
Bulk density	1600 kg/m^3
Gradation factor	2.95
The largest size	10 mm
The used additives:	aqueous solutions
Plasticizer (D1)	TamCem 60
Pre-calculation of concrete composition	
Water-cement ratio WCR	0.44
Plasticizer D1 (TamCem 60)	TC = 1%
Consumption of materials per 1 m3 of concrete mixture	on dry materials
Cement (C), kg; screening (S), kg	C-480; S = 1650
Water (W), kg; TamCem 60 (D1) additive, grams;	W = 211; D1 = 4800.

during the mining operations. The low capacity of the used machines, complexity of their design and high parts wear has been observed. The washed aggregates should be dried to the required moisture content.

The low efficiency of shotcrete support widely used at mines of Kazakhmys Corporation LLC has led to problems in the safety, the mining and sinking cycle. Thus, rock inrush in the working area, the design dimension violations of the workings, the increased time to secure the mine workings after blasting operations and the high yield of «the oversize» have been observed. As a result, it could lead to the high risks of injury to miners in the breakage and drifting faces, the detachment of rock slabs from the side walls or roof of the workings during the gadding, support and loading. In order to introduce the advanced technological solutions in the mining operations at the Kazakhmys Corporation LLP, the experimental and industrial tests of a sprayed

concrete mix with the Normet chemical additives have been performed to use at the Zhomart underground mine.

The main three objectives have been applied as part of the exploration:

1) rebound value should be measured;

2) the average thickness of the sprayed shotcrete layer during one drift should be determined;

3) the maximum layer thickness should be defined.

Research methods

The literary sources have been reviewed. The scientific and technical documentation on shotcrete supports of the mine workings have been studied. The pilot tests have been performed at the Zhomart mine. The research results with their critical evaluation to substantiate the further development and improvement of the studied object have been analyzed and generalized. The main used technical characteristics of the materials have been studied and described[6] [1, 2].

The tests have been conducted in two stages

1. The laboratory stage. The experimental laboratory concrete batches have been made. The batches have been done to determine the nominal composition for the currently used materials at the Zhomart mine and to define the working composition of concrete. This concrete would be used as the main one at the second stage of the pilot tests. The composition of the sprayed-concrete mix (selection map and certificates of quality for materials) has been selected. The control samples have been made to determine the parameters of the concrete mix.

2. The industrial stage. The pilot tests have been made. The industrial stage of tests has been performed with using the laboratory data. As a result, the developed mix has been directly applied in the existing process chain.

Results and discussion

Coordination and the general management of these tests have been provided by specialists[7] of Karat-Kazpribor LLP, Norservice LLP and commission of the Zhomart underground mine based on Table 3.

The dosing system for additives and inert materials has been lacking. Raw materials have been delivered in 1000 kg bags (cement, screenings) in the required proportion. TamCem 60 plasticizer has been directly added during preparation of the mix in the mixer. Then the mix has been delivered from a loading place by an underground mixer with capacity of 6 m^3 to the site of working operations. TamShot 80AF setting accelerator has been added into the concrete mix with using the automatic mode in the Spraymec shotcrete machine. The spraying with dosage of 8% by weight of the cement binder has been used. The visual observations have demonstrated that the mix was homogeneous and flowing P5. The roof and side walls of the workings have been flooded, and points of the active water occurrences have been observed. Shotcrete has been made from nozzle to surface of the workings (1.5...2 m for the side walls). Contact with the surface during the shotcrete time was good. The sliding and fluidity of sprayed concrete from side walls of the workings have not been observed. The average thickness of spraying during one drift from the side wall of the workings was 10-15 cm at an accelerator dosage of 8%. The average thickness of spraying on roof of the workings during one drift was 5 cm, including places with the active water leakage. The visual observation has demonstrated that the rebound was no more than 10-12%. The initial strength of the sprayed concrete has been measured with using the Civil Penetration (Figure 2). The strength was 227 kPa after 60 min, and it has been complied with class J1 by EN 14487-1.

The maximum spraying layer measured on side wall was about 22 cm. The working time to prepare 4.3 m^3 of mix (one mixer) was 30 min. Delivery time of the mix to workings was 60 min. The time for the anchoring operations including installation of the Spraymec unit and the mixer maneuvers was 90 min. Density[8] of the mix was 2238 g/cm^3. All properties of the mix and the spraying technology, e.g. a rebound of the mix, rheology, storage quality and dynamics of strength have been fully complied with «Instruction on arched support in mine workings at the Zhomart mine».

Conclusion

The selected fresh concrete has conformed to requirements of «Instruction on arched support in mine workings at the Zhomart mine» for 2020.

The operation of the mixing unit should be optimized as follows:

1) the quality control of the concrete mix with mixers, sampling, mix temperature measurement, density, etc.;

2) creation of quality control documents;

3) moisture control of aggregates, and adjustment of the water-cement ratio (WCR);

4) application of chemical additives;

5) hopper to store all inert materials.

The spraying technology should be optimized as follows:

1) introduction of the spraying quality evaluation system. It should control the thicknesses of supports led by the staff checker and take core samples to the laboratory;

2) coordination with the project institutes to use fibers in order to reduce the inrush;

3) training/raising of qualification for employees working in this direction with using the training device;

4) more elaborate preparation of the surface before spraying of a concrete layer (wash the spraying place with water/air to remove dust and dirt);

5) application of the starting mix before spraying;

6) the using of TamCrete CR concrete remover to clean machine units and mixers;

7) surface preparation before spraying (drainage systems in places of the active water inflows);

8) keeping the concrete flow log.

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[6] *Alejano R., Perucho Áu., Olalla C., Jiménez R. Rock engineering and rock mechanics: structures in and on rock masses. – CRC Press, 2014. – 372 p. (in English)*

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The article was prepared on the basis of pilot tests carried out by the commission of the Zhomart underground mine of «Kazakhmys Corporation» LLP and specialists of «Karat-Kazpribor» LLP, «Norservice» LLP.