УДК 622.273.21 DOI: 10.21440/0536-1028-2019-7-5-13

Developing the technology of mine stowing with processing tailings based hardening blends

Evgenii P. Volkov[1]*, Aleksandr N. Anushenkov[1]
[1] Siberian Federal University, Krasnoyarsk, Russia
e-mail: volkoff2@yandex.ru

Abstract

Introduction. *Large-scale implementation of mine stowing method is a relevant tendency to improve the technology of underground mining.*

Research aims *to develop and propose an effective technology of mine stowing with processing tailings based hardening blends.*

Research methods *include experimental investigation of mine stowing technology with processing tailing based hardening blends and the determination of basic characteristics of an artificial massif.*

Analysis*. The present work provides the results of research on conventional technologies of hardening blends preparations and the one developed by the authors; the results prove the effectiveness of hydropercussion-cavity activation of solution materials.*

Summary. *The analysis of the stowing manufacturing technologies under investigation has shown the effectiveness of the developed method based on the hydropercussion-cavity treatment of hardening blends materials.*

Key words: *underground mining; stowing; hardening blends; processing tailings; hydropercussion-cavity blending machine.*

Introduction. Practice and existing literature review [1–3] testify that the use of goaf stowing in definite mining-geological conditions is technically advisable and economically feasible when developing deposits of non-ferrous metal valuable ore, as well as coal and iron-ore deposits. And at the same time, important are the stowing systems for mineral extraction at great depths and in the areas of tectonic disturbances, where protection from rock pressure and rockbursts is impossible without the use of artificial massifs [4–8]. However, expensive cast hardening blends (CHB), manufacture technology and methods of delivering into the goaf restrain their application. Basic elements of cost of stowing are costs for binders.

Transition to low-grade integrated binders, search for some new cost-effective technologies of hardening blends manufacture promote stowing systems in mining practice thus becoming a relevant scientific and practical task.

Stowing prime-cost reduction should be ensured by the development of new technologies of mine stowing with gangue from various manufactures as binders and fillers.

The experience of stowage facilities operation shows that it is the milling technology that has become a frequent practice in hardening blends manufacture [9–11]. The main advantage of mills is their simple construction and maintenance together with high productivity. But they are metal- and power-intensive and distinguished by some functional restrictions in the efficient grinding fineness and finely dispersed homogenization of mill feed in aqueous media. According to the research, preparation of high-quality stowing blends with the use of fine tailings in ball mills does not make it possible to apply their complete fraction. Milling technology of hardening blends

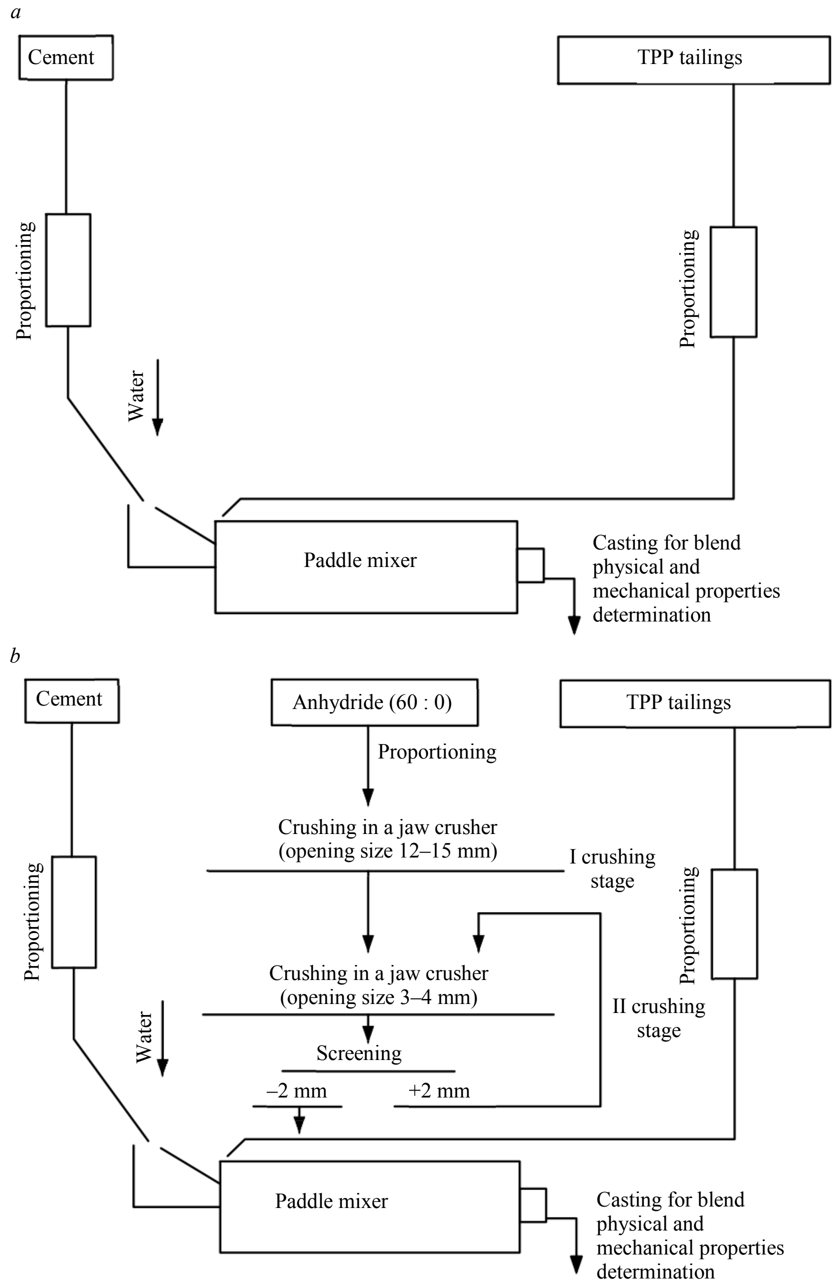


Fig. 1. A diagram of hardening blend preparation with a paddle mixer:
a – TC; *b* – ATC

Рис. 1. Схема приготовления твердеющей смеси с использованием лопастного смесителя:
a – ХЦ; *b* – АХЦ

manufacture with the use of processing tailings with less than 30 micrometer fraction content does not provide high quality stirring of components and their homogenization, which results in the reduction of binder properties and its over-expenditure.

Research methodology. In order to study various technologies of processing tailings stowing based blends preparation, experimental research of compositions of solid stowing solutions TC (processing tailings and cement) and ATC (anhydride,

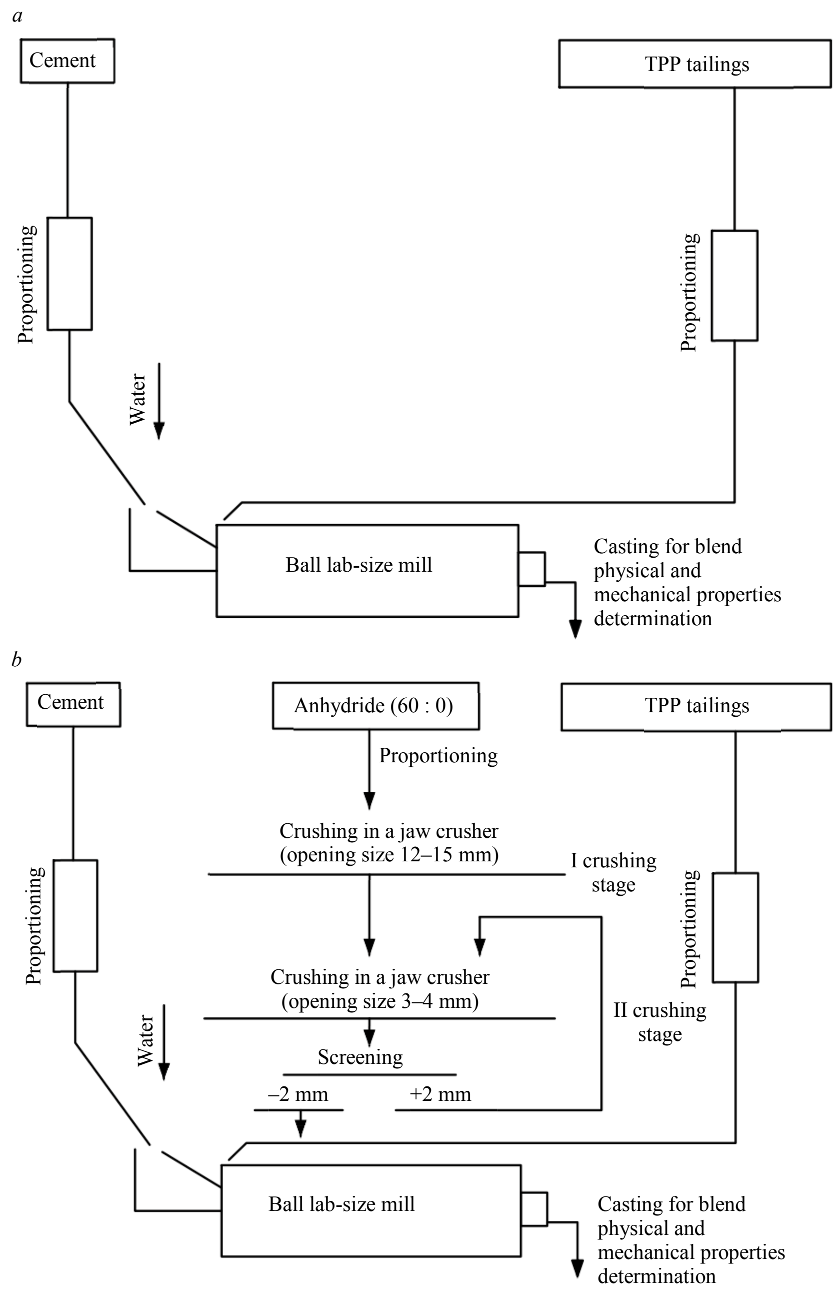


Fig. 2. A diagram of hardening blend preparation with a ball mill:
a – TC; *b* – ATC

Рис. 2. Схема приготовления твердеющей смеси с использованием шаровой мельницы:
a – ХЦ; *b* – АХЦ

processing tailings and cement) prepared with the following two methods: with the use of a paddle mixer (fig. 1, where TPP stands for the Talnakh processing plant) and a ball mill (fig. 2).

Research results. Specific consumption of materials, blend density, its fluidity and the strength of samples within the control period of concreting have been determined for all compositions under investigation (table 1, 2).

Results analysis has shown the dependence between the strength and fluidity of stowing compositions and the technology of grinding and homogenization of blend components and made it possible to determine a rational method of preparing CHB in ball mills.

Table 1. TC compositions with the use of a paddle mixer and a ball mill
Таблица 1. Составы ХЦ с использованием лопастного смесителя и шаровой мельницы

Preparation scheme	Materials consumption			Blend density t/m^3	Blend fluidity, mm (Suttard)	Density control characteristic, MPa			
	TPP tailings, kg/m^3	Cement, kg/m^3	Water, l			3 days	7 days	28 days	90 days
In a paddle mixer	1246	170	500	1.92	206	–	0.30	0.80	1.25
	1183	240	500	1.92	225	0.30	0.55	1.50	2.10
	1112	320	500	1.93	244	0.45	0.85	2.00	3.05
	1039	400	500	1.94	246	0.75	1.35	3.10	4.00
In a ball mill	1246	170	500	1.92	200	–	0.35	0.95	1.50
	1183	240	500	1.92	220	0.30	0.55	1.25	2.00
	1111	320	500	1.93	240	0.60	1.20	2.25	3.30
	1039	400	500	1.94	242	1.50	2.25	3.30	4.70

The main features of CHB manufacture in a ball mill include the fact that during grinding and stirring an active homogeneous part of the blend is formed with increased strength and rheological properties [12].

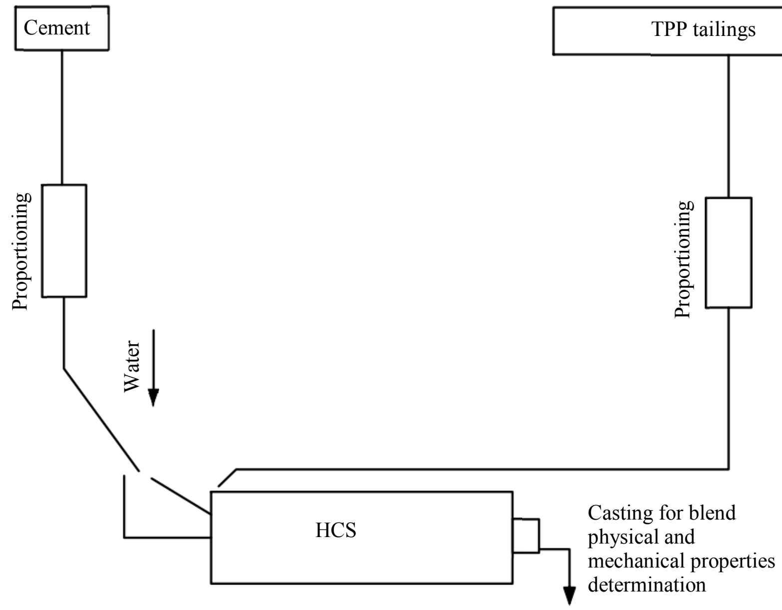
Table 2. ATC compositions with the use of a paddle mixer and a ball mill
Таблица 2. Составы АХЦ с использованием лопастного смесителя и шаровой мельницы

Preparation scheme	Materials consumption				Blend density t/m^3	Blend fluidity, mm (Suttard)	Density control characteristic, MPa			
	Anhydride, kg/m^3	TPP tailings, kg/m^3	Cement, kg/m^3	Water, l			3 days	7 days	28 days	90 days
In a paddle mixer	400	853	170	500	1.92	200	–	0.50	0.70	1.2
	600	657	170	500	1.93	203	–	0.70	1.00	1.8
	600	594	240	500	1.93	220	0.60	0.80	1.50	2.6
	400	718	320	500	1.94	223	0.70	1.00	1.70	2.8
	600	521	320	500	1.94	225	0.70	1.10	1.90	3.2
In a ball mill	400	853	170	500	1.92	195	–	0.60	0.85	1.5
	600	657	170	500	1.93	198	–	0.85	1.30	2.2
	600	594	240	500	1.93	215	0.70	1.05	1.85	3.3
	400	718	320	500	1.94	218	0.85	1.25	2.10	3.5
	600	521	320	500	1.94	220	0.90	1.40	2.35	4.0

CHB manufacture technologies with the use of a paddle mixer and a ball mill make it possible to ensure blend components hydration and crystallization processes development. However, at the same time, low intensity of simultaneous stirring of blend components does not ensure complete homogenization of CHB materials with the dispersed part of processing tailings, which results in the growth of binder consumption.

In order to provide the homogeny and intensity of components of CHB compositions under investigation, hydropercussion-cavity machines (HCM) may be efficiently applied in their production.

a



b

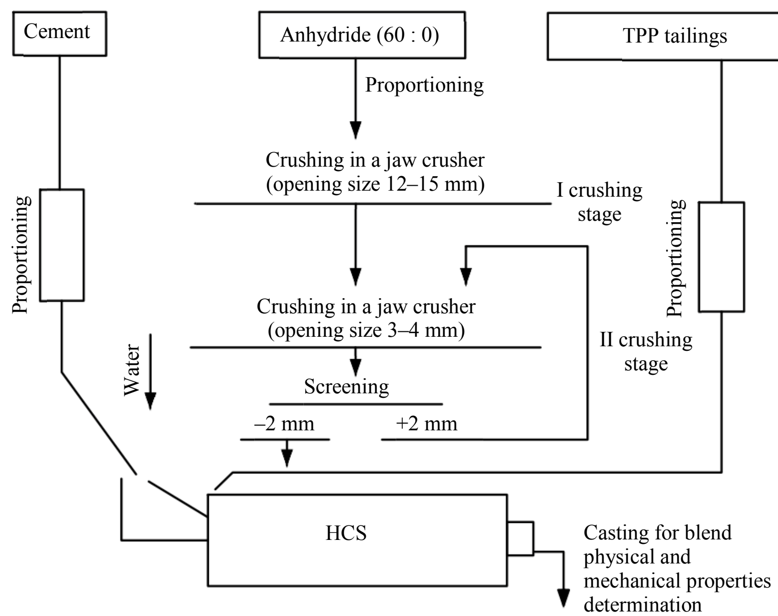


Fig. 3. A diagram of hardening blend preparation with HCS:
a – TC; *b* – ATC

Рис. 3. Схема приготовления твердеющей смеси с использованием ГКС:
a – ХЦ; *b* – АХЦ

HCM have currently found industrial application basically in mining industry [13]. The use of HCM promote to a significant economic benefit due to significant intensification of hydromechanical processes by means of reaching the hydropercussion-cavity mode of the treated blend, reduction of power- and material-intensity, reduced production facilities.

In order to study the impulse hydropercussion-cavity effect on the materials of CHB, hydropercussion-cavity separator (HCS) [14] and the related technology of preparing stowing blend.

Research has been carried out for two compositions of hardening blends TC and ATC according to the developed technology with the use of HCS (fig. 3).

Specific consumption of materials, blend density, its fluidity and strength of samples within the control period of concreting have been determined for the studied compositions (table 3).

Table 3. Compositions of TC and ATC with the use of HCS
Таблица 3. Составы ХЦ и АХЦ с использованием ГКС

Materials consumption				Density control characteristic, MPa		
Anhydride, kg/m^3	TPP tailings, kg/m^3	Cement, kg/m^3	Water, l	7 days	28 days	90 days
–	1246	170	500	0.5	1.2	2.0
–	1183	240	500	0.7	1.6	2.6
–	1112	320	500	1.6	2.9	4.3
–	1039	400	500	2.9	4.3	6.1
400	853	170	500	0.9	1.6	2.4
600	657	170	500	1.2	2.0	2.9
600	594	240	500	1.4	2.5	3.8
400	718	320	500	1.7	3.0	4.4
600	521	320	500	1.9	3.3	4.7

The obtained results have shown that CHB preparation with the use of hydropercussion-cavity separator allows ensuring high-quality activation and homogenization of stowing compositions.

Table 4. The distribution of the phases of textural features of CHB with the use of HCS, g/cm^3
Таблица 4. Распределение фаз структурных образований ЛТС с использованием ГКС, г/см^3

Mineral	Formula	TC composition			ATC composition		
		3 days	7 days	28 days	3 days	7 days	28 days
Clinochlore	$(Mg, Al, Fe)_6 (Si, Al)_4 O_{10} (OH)_8$	9.8	15.5	16.3	6.1	8.6	12.0
Brownmillerite	$Ca_2 (Al, Fe)_2 O_5$	3.9	0.0	0.0	1.4	0.0	0.0
Quartz	SiO_2	7.8	9.4	14.4	6.1	7.7	11.6
Diopside	$CaMgSi_2O_6$	25.1	36.3	45.9	3.3	9.1	11.1
Gypsum	$Ca(SO_4)\ 2(H_2O)$	24.0	26.9	34.0	58.3	68.7	71.0
Jarosite	$K\ Fe_3 (SO_4)_2 (OH)_6$	6.8	7.2	9.8	6.1	6.8	7.3
Ettringite	$Ca_6Al_2 (SO_4)_3 (OH)_{12}\ 26H_2O$	13.2	17.5	22.9	15.3	25.3	27.1

X-ray phase ad X-ray structure analysis of crystallization processes on the terms of strength gain has revealed that the compositions of ATC, which harden by means of crystallization of anhydride and new formations within (table 4), in the course of processing tailings and cement and anhydride interaction, gain maximum strength after hydropercussion-cavity treatment (table 1–3).

Results analysis. In the course of the research it has been stated that the content of fine fractions in stowing formulations in processing tailings ensure the manifestation of their binding properties and the increased strength gain of the hardening blends when they are treated within the action of hydropercussion-cavity impulses.

Research results testify that the developed technology of processing tailings based CHB manufacture with the use of HCS allows ensuring high intensity of blend finely dispersed components simultaneous stirring, their homogenization and the refreshment of the hydrating surfaces, which result in the improvement of stowing strength and its increased gain.

Summary. Based on the research, it has been stated that the samples of stowing blends which have been prepared by the milling method, are generally 20% stronger than the samples prepared with the use of a paddle mixer. At the same time, stowing blend samples, prepared according to the technology with a hydropercussion-cavity machine are generally 30% stronger than the samples prepared with the use of a milling method.

The developed technology of mine stowing [15] thus ensures the improvement of hydrating level and the activation of stowing blends components, which results in the increased activity of CHB components and strength of the artificial massif.

REFERENCES

1. Bitimbaev M. Zh., Krupnik L. A., Shaposhnik Iu. N. *Theory and practice of stowing when developing mineral deposits*. Almaty: Dauir Publishing; 2012. (In Russ.)
2. Krupnik L. A., Shaposhnik Iu. N., Shaposhnik S. N., Tursunbaeva A. K. Technology of stowing at mining enterprises of Kazakhstan. *Fiziko-tekhnicheskie problemy razrabotki poleznykh iskopaemykh = Journal of Mining Science*. 2013; 1: 95–105. (In Russ.)
3. Chen G. Y. and Huang W. H. Investigation on blending CFB ash with blast furnace slag as replacement for Portland cement used in concrete binders. *Adv. Mater. Res*. 2013; 723: 623–629.
4. Kroupnik L., Abdykalykova R., Elemesov K., Sładkowski A., Shaposhnik Yu., Shaposhnik S. Combined pipeline transport for hardening filling Mixtures. VIII Int. Conf. "Transport Problems". Catowice, Poland, 2016. P. 258–265.
5. Deng D. Q., Liu L., Yao Z. L., Song K. I., and Lao D. Z. A practice of ultra-fine tailings disposal as filling material in a gold mine. *J. Environ. Manage*. 2017; 196: 100–109.
6. Hu S. G., Lu X. J., Niu H. L. and Jin Z. Q. Research on preparation and properties of backfilling cementation material based on blast furnace slag. *Adv. Mater. Res*. 2011; 158: 189–196.
7. Krupnik L. A., Shaposhnik Iu. N., Shaposhnik S. N. The development of backfilling technology in terms of Novo-Leninogorsky mine planning. *Gornyi informatsionno-analiticheskii biulleten (nauchno-tekhnicheskii zhurnal) = Mining Informational and Analytical Bulletin (scientific and technical journal)*. 2015; 8: 25–32. (In Russ.)
8. Ke X., Zhou X., Wang X., Wang T., Hou H., and Zhou M. Effect of tailings fineness on the pore structure development of cemented paste backfill. *Constr. Build. Mater*. 2016; 126: 345–350.
9. Grebenkin S. S., Melnik V. V. *Advanced technologies of underground mining of mineral deposits reserves with goaf stowing*. Donetsk: VIK Publishing; 2013. (In Russ.)
10. Nikolaev E. I., Gultiaev V. G., Kozhbanov K. Kh. New technology of preparing hardening blend at Orlovsky mine. *Gornyi zhurnal = Mining Journal*. 2002; 5: 58–60. (In Russ.)
11. Krupnik L. A., Shaposhnik Iu. N., Shaposhnik S. N. The prospects of stowing transportation to the shaft at mining enterprises in Kazakhstan. *Gornoe oborudovanie i elektromekhanika = Mining Equipment and Electromechanics*. 2015; 4: 21–28. (In Russ.)
12. Volkov E. P., Anushenkov A. N., Guzanov P. S., Lytneva A. E. Stowing solutions based on ore processing gangue in the systems of Norilsk industrial region deposits underground mining systems. *Gornyi zhurnal = Mining Journal*. 2015; 6: 85–87. (In Russ.)
13. Balabyshko A. M. *Rotor devices with flow modulation and their application in the industry*. Moscow: Nedra Publishing; 1992. (In Russ.)
14. Volkov E. P., Stovmanenko A. Iu., Anushenkov A. N. *Mixing-activating device for liquid media*. Patent RF no. 2550609; 2015.
15. Anushenkov A. N., Volkov E. P., Stovmanenko A. Iu. *A method of preparing cast hardening stowing blends based on the finely-dispersed filler*. Patent RF no. 2607329; 2017.

Received 2 July 2019

Information about authors:

Evgenii P. Volkov – senior lecturer, Department of Underground Mining, Institute of Mining, Geology and Geotechnology, Siberian Federal University. E-mail: volkoff2@yandex.ru

Aleksandr N. Anushenkov – DSc (Engineering), Professor, Head of the Department of Underground Mining, Institute of Mining, Geology and Geotechnology, Siberian Federal University. E-mail: aanushenkov@sfu-kras.ru

DOI: 10.21440/0536-1028-2019-7-5-13

Разработка технологии закладки горных выработок твердеющими смесями на основе хвостов обогащения

Волков Е. П.[1], Анушенков А. Н.[1]
[1] Сибирский федеральный университет, Красноярск, Россия.

Реферат

Введение. *Актуальным направлением совершенствования технологии подземных горных работ является широкое внедрение систем разработки с закладкой выработанного пространства.*
Цель работы. *Разработать и рекомендовать эффективную технологию закладки горных выработок твердеющими смесями на основе хвостов обогащения.*
Методы исследования. *Проведение экспериментальных исследований технологий закладки горных выработок твердеющими смесями на основе хвостов обогащения с определением основных характеристик искусственного массива.*
Анализ. *В представленной работе приведены результаты исследований традиционных технологий приготовления твердеющих смесей и разработанной авторами, подтверждающие эффективность гидроударно-кавитационной активации материалов смеси.*
Заключение. *Анализ исследуемых технологий производства закладки показал эффективность разработанного способа, основанного на гидроударно-кавитационной обработке материалов твердеющих смесей.*

Ключевые слова: *подземная разработка; закладка; твердеющие смеси; хвосты обогащения; гидроударно-кавитационный смеситель.*

БИБЛИОГРАФИЧЕСКИЙ СПИСОК

1. Битимбаев М. Ж., Крупник Л. А., Шапошник Ю. Н. Теория и практика закладочных работ при разработке месторождений полезных ископаемых. Алматы: Дауiр, 2012. 624 с.
2. Крупник Л. А., Шапошник Ю. Н., Шапошник С. Н., Турсунбаева А. К. Технология закладочных работ на горнодобывающих предприятиях Республики Казахстан // ФТПРПИ. 2013. № 1. С. 95–105.
3. Chen G. Y. and Huang W. H. Investigation on blending CFB ash with blast furnace slag as replacement for Portland cement used in concrete binders. Adv. Mater. Res. 2013. Vol. 723. P. 623–629.
4. Kroupnik L., Abdykalykova R., Elemesov K., Sładkowski A., Shaposhnik Yu., Shaposhnik S. Combined pipeline transport for hardening filling Mixtures. VIII Int. Conf. "Transport Problems". Catowice, Poland, 2016. P. 258–265.
5. Deng D. Q., Liu L., Yao Z. L., Song K. I., and Lao D. Z. A practice of ultra-fine tailings disposal as filling material in a gold mine. J. Environ. Manage. 2017. Vol. 196. P. 100–109.
6. Hu S. G., Lu X. J., Niu H. L. and Jin Z. Q. Research on preparation and properties of backfilling cementation material based on blast furnace slag. Adv. Mater. Res. 2011. Vol. 158. P. 189–196.
7. Крупник Л. А., Шапошник Ю. Н., Шапошник С. Н. Разработка технологии закладочных работ на проектируемом Ново-Лениногорском руднике // ГИАБ. 2015. № 8. С. 25–32.
8. Ke X., Zhou X., Wang X., Wang T., Hou H., and Zhou M. Effect of tailings fineness on the pore structure development of cemented paste backfill. Constr. Build. Mater. 2016. Vol. 126. P. 345–350.
9. Гребенкин С. С., Мельник В. В. Прогрессивные технологии подземной отработки запасов месторождений полезных ископаемых с закладкой выработанных пространств. Донецк: ВИК, 2013. 752 с.
10. Николаев Е. И., Гультяев В. Г., Кожбанов К. Х. Новая технология приготовления твердеющей закладки на Орловском руднике // Горный журнал. 2002. № 5. С. 58–60.
11. Крупник Л. А., Шапошник Ю. Н., Шапошник С. Н. Перспективные направления транспортирования закладочной смеси в шахту на горнодобывающих предприятиях Казахстана // Горное оборудование и электромеханика. 2015. № 4. С. 21–28.
12. Волков Е. П., Анушенков А. Н., Гузанов П. С., Лытнева А. Э. Закладочные смеси на основе отходов обогащения руд в системах подземной разработки месторождений Норильского промышленного района // Горный журнал. 2015. № 6. С. 85–87.
13. Балабышко А. М. Роторные аппараты с модуляцией потока и их применение в промышленности. М.: Недра, 1992. 176 с.
14. Смесительно-активирующее устройство для жидких сред: пат. 2550609 Рос. Федерация. № RU 2 550 609 C1; заявл. 28.03.2014; опубл. 10.05.2015. Бюл. № 13. 6 с.
15. Способ приготовления литых твердеющих закладочных смесей на основе мелкодисперсного заполнителя: пат. 2607329 Рос. Федерация. № RU 2 607 329 C1; заявл. 30.11.2015; опубл. 10.01.2017. Бюл. № 1. 8 с.

Поступила в редакцию 2 июля 2019 года

Сведения об авторах:

Волков Евгений Павлович – старший преподаватель кафедры подземной разработки месторождений Института горного дела, геологии и геотехнологий Сибирского федерального университета. E-mail: volkoff2@yandex.ru
Анушенков Александр Николаевич – доктор технических наук, профессор, заведующий кафедрой подземной разработки месторождений Института горного дела, геологии и геотехнологий Сибирского федерального университета. E-mail: aanushenkov@sfu-kras.ru

Для цитирования: Волков Е. П., Анушенков А. Н. Разработка технологии закладки горных выработок твердеющими смесями на основе хвостов обогащения // Известия вузов. Горный журнал. 2019. № 7. С. 5–13 (In Eng.). DOI: 10.21440/0536-1028-2019-7-5-13
For citation: Volkov E. P., Anushenkov A. N. Developing the technology of mine stowing with processing tailings based hardening blends. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = News of the Higher Institutions. Mining Journal*. 2019; 7: 5–13. DOI: 10.21440/0536-1028-2019-7-5-13