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Management of hardening mixtures properties when stowing mining sites of ore deposits

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Underground mining is characterized by the weakening of the bearing rock mass strata competence and the accumulation of mineral waste. The full use of subsurface resources is ensured by the use of technologies with filling voids by hardening mixtures, which requires high-quality raw materials to obtain the required strength. The deficit of the binding component can be filled with the use of granulated slags of blast-furnace process, mill tailings, ash-slags and other wastes. Most often, voids are laid by mixtures with a combination of cement and a binding component. Mixtures with ash-slag additives to cement in an equivalent amount are not inferior to the strength of the mixture only with cement, especially when grinding ash-slag.

The properties of stowing rock masses when using composite binding components and inert fillers are controlled by mechanical, chemical, physical and energy effects at the stages of preparation and transportation of hardening mixtures. To obtain the active fraction of cement substitutes, disintegrators are used that apply the inertia forces of materials at a high speed of rotation with an increase in high activity indicators and lower energy costs.

The components of hardening mixtures can be the majority of waste from mining and related industries, which is determined experimentally in specific conditions.

Key words: underground mining; mineral waste; hardening mixture; activator; strength; properties; disintegrator; mill

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Introduction. Solid minerals output from the subsurface is characterized by subsidence of the land surface above the working out field and accumulation of mining and processing waste, which negatively affects the ecology of adjacent areas, changes the landscape and leads to the exclusion of land from circulation.

The lowest damage to the earth's surface is caused by development technologies with the stowing of the mining sites with hardening mixtures that minimize deformations of the bearing rock mass strata. Expanding the scope of these technologies is a priority for the mining production development [3, 4, 9].

The main disadvantage of using a hardening stowing mixture – the high cost – can be reduced when using waste products as additives to binding cement and inert aggregates in the use mixture.

Mining enterprises have accumulated significant amounts of rock mass from underground operations, mill tailings, ash-slag from boiler houses or CHP and other solid and liquid waste. The possibility of their use is the subject of numerous studies by Russian and foreign scientists. In the mining of metal ores, a tool to improve the completeness of subsurface use is a technology void filling hardening mixture, which are used in the mill tailings, mineral processing and waste related industries, what can reduce the negative impact on the environment [7, 11-12].

Formulation of the problem. The rational scope of application of hardening mixtures using mining waste is determined by the sum of technological capabilities, economic feasibility and environmental safety. For their combination, it is necessary to substantiate the parameters of the technology of preparation and transport of stowing mixtures oriented to new components, optimize the operation modes of stowing complexes, and control the properties of stowing mixtures at all stages of mining operations.

Methodology. Taking into account the variety of wastes involved in production and the research capabilities of mining enterprises, methods for solving the problem include scientific generalization, systematization, selection and justification of new parameters, experimental verification of the results and recommendations for their use.

Cost and other parameters of the developed technology are refined by modeling individual processes and comparing them with experimental data.

Discussion. The most common suitable for use as a binding component are granulated slags of blast furnace process, mill tailings, phosphogypsum from the fertilizer manufacturing, sludge of aluminum production, ash-slags and others (Table 1) [1-4, 6-8].

Table 1

Compositions of hardening mixtures of various strengths

Components, kg/m^3	Options with a strength of up to 1.8 MPa			Options with a strength of up to 3 MPa		
	1	2	3	1	2	3
Portland cement or slag-portland cement M-400	30	–	100	60	30	140
Wet-ground granulated blast furnace slag	420	–	–	390	–	–
Wet-ground coal-fired boiler house ash-slag	–	200	300	–	170	260
Cement kiln dust	–	250	–	–	250	–
Inert aggregate	1300	1300	1300	1300	1300	1300
Water, l/m^3	360	400	420	360	400	420
Plasticizer	0.3	0.3	0.3	0.3	0.3	0.3

Most often, voids are stowed with mixtures with a combination of cement and a binding additive to it (Table 2).

Table 2

Compositions of hardening mixtures with a combined binding component

Components of the mixture, kg/m^3						Viscosity, sm	Water gain, %	Maximum shear stress, Pa	Strenght, MPa, age, s		
Portland cement		Wet-ground slag	Sand-gravel aggregate	Ash-slag	Water, l/m^3						
M-400	M-500								7	14	28
30	–	420	1275	–	300	16,5	1,7	83	–	3.38	5.66
60	–	390	1253	–	370	16.5	1.4	94	3.75	5.22	7.1
30	–	420	688	320	395	17	1.6	97	2.86	3.49	3.98
60	–	390	707	320	390	16	1.6	80	3.74	4.7	5.64
–	30	420	1275	–	360	16	1.4	–	3.34	4.26	5.97
–	60	390	1253	–	370	17	1	111	4.13	5.57	7.32
–	80	370	1294	–	355	17	1	112	4.32	6.2	9.59
–	30	420	638	320	395	17	2.3	67	2.39	3.87	5.13
–	60	390	707	320	390	17	2	54	3.84	5.33	7.1
–	80	370	734	320	330	14	0.7	107	3.77	5.78	6.87

Experience with the use of hardening mixture compositions with granulated slag Portland cement binder and additive from low active waste allows us to draw the following conclusions:

- the minimum consumption of M-400 cement in high-strength compounds is 30 kg/m^3;
- increasing the cement grade from M-400 to M-500 reduces the cement consumption in the complex binding component while ensuring the same strength of the mixture;
- partial replacement of the sand-gravel aggregate (SGA) with ash-slag (up to 30 %) reduces the strength, but provides waste disposal and reduces the cost of filler;
- compositions with ash-slags ground in a ball mill (30 % of the fraction – 0.08 mm), other things being equal, have greater strength than with non-ground ash-slags;
- the minimum consumption of cement with ground ash-slags is 130-143, and with non-ground – 140-160 kg/m^3.

Given the increased binding capacity and reserves of ash-slag, they are prioritized for use as an additive to cement (Table 3).

Table 3

Compositions of hardening mixtures with a binding component from ash-slag

Components, kg/m^3						Maximum shear stress, Pa	Strength in 28 s, MPa
Cement	Ash-slag		Screenings	SGA	Water, l/m^3		
	non-ground	ground					
200	–	–	700	790	330	100	2.9
180	–	–	790	800	330	120	3
160	–	–	800	790	330	130	2.5
180	–	–	1180	400	330	100	2.7
160	–	–	1200	400	330	100	3
180	–	–	390	1210	330	120	3.1
160	–	–	400	1220	330	140	2.2
140	310	–	–	1065	440	100	2.3
160	290	–	–	1065	440	100	2.4
140	310	–	1065	–	490	110	1.7
160	290	–	1065	–	480	100	2.1
140	–	310	–	1120	416	40	2.9
160	–	290	–	1130	400	40	4.7
140	–	310	1120	–	480	50	2.7
160	–	290	1130	–	450	50	4.1

The mixture with additives of ash-slag in an equivalent amount to cement is inferior in strength to the mixture only with cement, especially when grinding the ash-slag. This can be explained by the properties of ash-slags that are more favorable for the hydration process.

Physical and mechanical properties of the binding components of the mixture:

Components	Density, kg/m^3	Bulk density, kg/m^3	Sieve residue 5 mm, %	Specific surface area, m^2/kg	Fineness modulus
Granulated slag	2330	1410	8.3	7.67	3.2
Ash-slag current	2130	570	25.2	239.6	1.04
Ash-slag waste	2170	530	23.6	253.2	1.11

The properties of stowing rock masses are controlled by increasing the activity of the hardening mixtures components by mechanical, chemical, physical and energy effects and also the composition of the mixture [5, 6, 10].

When activating additives to cement in the UDA-10 disintegrator with a total counter processing speed of 35-130 m/s, the output of 40-60 % of particles with a size of 0.08 mm is provided. Even with a total linear counter speed of 62 m/s, the fineness of the ash-slag grinding sufficient for cement addition is ensured, because the specific surface of the ash-slag exceeds the specific surface of the cement by almost 1.5 times.

For dry slags grinding to the required fineness (passing of 50-60 % of particles through a sieve-0.08 mm), a disintegrator with a total linear counter processing speed of 160 m/s can be used.

Activation of granulated slag in a semi-industrial disintegrator JB-12 at a speed of 1100-1700 rpm with a total linear counter velocity of 77-120 m/s showed results identical to the activation results in UDL-10.

Ash-slag was processed in a semi-industrial disintegrator D-27 with three-row self-lining blade rotors with an outer diameter of 615 mm.

The humidity of the treated ash slag is 9 %. The fineness of the grinding was 35.6 % of the active fraction. The strength of the solid stowing of 3 MPa is obtained at a cement consumption of 130 kg/m^3. The water consumption of 330 l/m^3 was insufficient, so the solid stowing had a large value of the maximum shear stress. Increasing the water to 400 l/m^3 significantly reduced the strength of the mixture.

Granulated slag KS-0.08 was processed in a D-27 disintegrator without cement and together with cement (Table 4).

Table 4

Parameters of the solid stowing on a complex binding component with activation in the disintegrator

Components of the mixture, kg/m^3					Maximum shear stress, Pa		Viscosity, sm	Water sludge coefficient	Density, kg/m^3	Strength, MPa age, s	
Cement	Granulated slag	Ash-slag	SGA	Water	Sand	SGA				14	28
Compositions on granulated slag-Portland cement binder											
80	370	–	1372	330	25	76	17.5	91.9	1970	3.5	6.2
60	390	–	1371	330	60	81	16	90.8	2000	3.1	5
40	410	–	1368	330	55	31	17.5	90.8	2010	2.7	3.9
20	430	–	1366	330	56	217	16	91.6	1990	1.1	2.1
Compositions on ash-slag Portland cement binder											
160	–	290	1370	330	116	178	15.5	93.9	1770	3.9	4.8
140	–	310	1370	330	102	180	16	96	1700	2.6	3.9
120	–	330	1370	330	98	185	17	95.2	1660	1.9	2.8
100	–	350	1370	330	117	187	15	94.9	1640	1.3	2.1
80	–	370	1370	330	138	172	15	93.5	T620	0.91	1.5
60	–	390	1370	330	119	169	15.5	94.8	1610	0.58	0.72
150	–	300	1093	395	105	132	18	3.2	1650	3.65	4.25
130	–	320	1086	395	90	143	18.5	3.6	1630	2.4	3.3
110	–	340	1078	395	128	165	16.5	3.2	1630	1.75	2.3

The amount of grinding slag fineness significantly affects the properties of the mixture and the strength of the solid stowing. Activation of the granule in the disintegrator increases the strength of the hardening mixture in comparison with grinding in a drum mill due to the application of high energy (Table 5).

Table 5

Granulometric composition of activated granulated slag

Sieve residue, mm, %								Passing through the sieve, mm, %		Specific surface area, m^2/kg	
1.6	1	0.63	0.40	0.315	0.2	0.16	0.1	0.1	0.08	0.1	Total
Processing in a disintegrator											
–	0.22	1.24	2.87	3.25	9.27	5.13	13.38	64.64	52.3	158.4	110.1
0.16	0.44	0.08	4.40	5.58	13.49	5.26	12.49	55.69	40.8	137.9	88.4
Processing in a drum mill											
–	–	0.04	0.08	2.67	16.78	9.99	19.01	51.45	39.9	148.2	88.4

Ash-slag was processed in a D-27 disintegrator at 2900/3000 rpm (total linear counter speed of 118.8 m/s). The total consumption of the binding component is 450 kg/m^3. SGA was used as a filler. The components were mixed manually. The parameters of hardening mixtures on a complex binding component with different grinding fineness are summarized in Table 6.

The results of experiments allow us to draw conclusions:

- the strength of hardening mixtures of 3 MPa with a binding component made of granulated slag is provided with a minimum cement consumption of 30-40 kg/m^3;
- the joint wet treatment of granulated slag and cement practically does not affect the strength of the solid stowing, although it is slightly lower when wet processing;
- wet treatment compared to dry treatment increases the energy consumption of disintegrating by 1.5 times and increases rotor wear by 20-30 %.

Table 6

Properties of hardening mixtures on a complex binding component with different grinding fineness

Components of the mixture, kg/m^3				Viscosity, sm	Maximum shear stress, Pa		Water gain, % for 1.5 h	Density of stowing, kg/m^3	Strength, MPa age, s	
Cement	Granulated slag	SGA	Water		Without the gravel	SGA			14	28
Fineness 57 %										
80	370	1371	330	17.5	25	76	5	1970	3.5	6.2
Fineness 52 %										
80	370	1291	360	20	69	102	7	2900	3.05	5.35
80	370	1371	330	18	89	124	5.2	1996	3.3	5.7
Fineness 41 %										
80	370	1291	350	20.5	74	113	9.1	2000	2.5	4
80	370	1371	330	17.5	83	130	7.5	2010	2.7	4.4
Fineness 40 %										
80	370	1291	360	20	80	130	9.2	1990	2.3	3.8
80	370	1371	330	18	91	135	7.7	2005	2.45	4.06

To assess the dependence of the hardening mixtures properties on the intensity of mixing, granulated slag was activated in a D-27 disintegrator at a speed of 30 m/s (Table 7-8).

Table 7

The compositions of the mixture on granulated slag-Portland cement binder

Components of the mixture, kg/m^3				Viscosity, sm	Maximum shear stress, Pa	Water gain, % for 1.5 h	Density, kg/m^3	Strength, MPa age, s			
Cement	Granulated slag	SGA	Water					7	14	28	60
Double wet processing of granulated slag											
80	370	1358	325	20	115	4.9	1925	1.5	3.1	5.8	8.5
60	390	1345	320	20	113	4.2	1910	1.52	2.75	4.7	7
40	410	1332	315	20	121	4.1	1915	0.9	2.1	3.6	4.8
Double joint wet processing of granulated slag and cement											
80	370	13138	325	20	106	3.8	1905	1.3	2.9	5.6	8.3
60	390	1345	320	20	112	3.5	1900	1.1	2.6	4.9	7.2
40	410	1332	315	20	119	3.4	1900	0.9	2.4	3.8	4.9

Table 8

The compositions of the mixture on ash-slag Portland cement binder

Components of the mixture, kg/m^3					Viscosity, sm	Maximum shear stress, Pa	Water gain, % for 1.5 h	Density, kg/m^3	Strength, MPa age, s			
Cement	Ash-slag	Screenings	SGA	Water					7	14	28	60
Wet processing												
180	370	–	1319	325	13.5	166	2.9	1925	2.9	3.9	4.8	7.8
140	390	–	1306	320	12.8	181	2.2	1910	1.6	2.3	3.1	5.4
100	350	–	1293	315	12.5	190	3.2	1915	1	1.5	2.3	3.1
Joint wet processing of ash-slag and cement												
180	270	–	1319	325	12	218	3.8	1905	2.4	3.4	4.2	7.5
140	310	–	1306	320	13	169	3.5	1900	1.3	2.1	2.8	4.7
100	350	–	1293	315	12.5	198	3.4	1900	0.9	1.3	2.1	2.9
Joint wet processing of all components												
180	270	1117	–	400	14.5	89	2	1615	1.7	2.5	3.7	6.5
140	310	1104	–	400	16	126	3.1	1620	1.2	1.7	2.5	4.7
100	350	1090	–	40	16.8	106	2.8	1625	0.9	1.3	1.9	3.3

Mixtures of equal composition were mixed with different intensities: in a disintegrator and manually (Table 9).

Table 9

Compositions of the hardening mixture with mixing

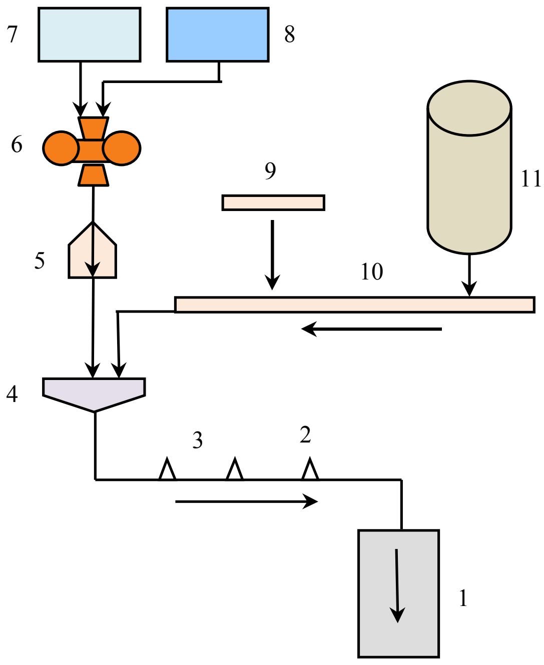
Components of the mixture, kg/m^3				Viscosity, sm	Maximum shear stress, Pa	Water gain, % for 1.5 h	Density, kg/m^3	Strength, MPa age, s			
Cement	Granulated slag	CSS	Water					7	14	28	60
Intensive mixing in the D-27 disintegrator											
80	370	1165	404	15.5	143	4.2	1925	1.1	2.5	3.9	7.3
60	390	1165	404	16.5	136	6.3	1900	0.9	2	3.2	6
40	410	1161	404	17.5	101	6.5	1875	0.7	1.6	2.6	5.1
60	340	1218	401	18.5	86	6	1880	1	2.3	3.1	5.3
60	240	1327	395	18.2	94	5.2	1840	0.8	1.6	2.3	4.1
60	140	1434	390	17	102	4.6	1855	0.5	0.9	1.3	2.3
Mixing manually											
80	370	–	425	19.5	96	8.8	1830	–	2.2	3.4	4.9
60	390	–	425	18.5	106	9	1855	–	1.9	2.8	4.1
40	410	–	425	18.5	112	8	1890	–	1.4	2.1	3.2
60	340	1117	418	16.5	184	7.8	1890	–	2.1	3.1	4.8
60	240	1104	412	15.5	201	7.4	1890	–	1.4	2.1	3.2
60	140	1090	406	15	214	7	1875	–	0.8	1.1	1.7

Note. CSS – crushed-stone screenings.

The results of experiments allow us to draw conclusions:

- by intensive mixing of the hardening mixture based on CSS in the disintegrator, the cement consumption can be reduced from 60 to 50 kg/m^3;
- with a decrease in the consumption of granulated slag at the same consumption of cement the strength of the solid stowing decreases regardless of the intensity of mixing;
- the minimum consumption of a complex binder with a fine aggregate based on CSS is 400 kg/m^3.

Increasing the activity of hardening mixtures is carried out during the preparation and transportation of hardening mixtures (see the Figure).



Activation scheme for hardening mixtures during production and transportation
1 – block camera; 2 – shaker machines ; 3 – stowing pipeline; 4 – mixer; 5 – vibration mill; 6 – desintegrator; 7 – blast furnace slag hopper; 8 – activated water of gauging; 9 – vibrating screen of inert fillers; 10 – conveyor; 11 – cement hopper

To obtain the active fraction of slag substitutes for cement, disintegrators are used that have the inertia forces of materials at high rotational speeds to achieve higher activity rates with less energy consumption.

In the disintegrator of the Shokpak deposit's stowing complex in Northern Kazakhstan, granulated slag was activated for seven years with a total linear counter velocity of up to 450 m/s. Processing in a disintegrator allows to obtain a 50 % binder by volume with a grain size of 0.076 mm from granulated slag of 20 mm.

The grinding fineness in the disintegrator 40-60 % of the active fraction output was provided when grinding granulated blast furnace slag of the K-0.8 grade and ash-slag with a total counter speed of about 100 m/s. Data about the hardening mixture properties are summarized in Table 10.

Table 10

Strength of the hardening mixture based on activated slag

The consumption of components, kg/m^3					Shear stress, MPa	Strength in 28 s, MPa
Cement	Slag	Sand	Clay loam	Water		
40	–	1490	–	400	6	0.2
60	–	1470	–	400	11	0.3
80	–	1455	–	400	12.6	0.4
100	–	1440	–	400	9	0.7
120	–	1423	–	400	12.5	1.1
150	–	1400	–	400	12.5	1.3
180	–	1426	–	400	13	1.2
200	–	1360	–	400	9.5	2.6
140	–	941	235	500	48	0.8
160	–	928	231	500	29	0.8
180	–	915	228	500	47	1
200	–	982	225	500	37	1.5
220	–	890	222	500	27	1.8
140	–	524	522	550	30	0.8
160	–	516	514	550	27	0.3
180	–	507	505	550	50	1
200	–	500	497	550	38	1.5
140	–	–	660	700	20	0.4
160	–	–	643	700	10	0.4
180	–	–	630	700	10	0.6
200	–	–	610	700	10	1.2
30	300	1375	–	380	12	0.6
30	270	1405	–	380	11.5	0.56
30	250	1425	–	380	11.5	0.62
30	220	1455	–	380	11	0.46
60	250	1395	–	380	12.5	0.65
60	190	455	–	380	11.5	0.53

The obtained results can be used in selecting and justifying the systems for developing ore deposits with stowing [13-16].

Conclusions.

1. The concept of the humanizing attitude to the subsurface as a priority direction includes the use of stowing hardening mixtures in mining production to improve the quality of extracted raw materials and reduce the burden on the environment.
2. The majority of waste from mining and related industries can be components of stowing hardening mixtures.
3. The activity of the hardening mixtures ingredients is adequately increased by processing in disintegrators, which allows to control the quality of the stowing rock mass.

REFERENCES

1. Ermolovich O.V., Ermolovich E.A. Composite stowing materials with the addition of mechanically activated waste. *Izvestiya TulGU. Nauki o Zemle*. 2016. Iss. 3, p. 24-30 (in Russian).

2. Guzanov P.S., Lytneva A.E., Anushenkov A.N., Volkov E.P. Stowing mixtures based on ore dressing waste in underground mining systems of the Norilsk industrial district. *Gornyi zhurnal*. 2015. N 6, p. 85-88 (in Russian).

3. Kaplunov D.R., Melnik V.V., Rylnikova M.V. Comprehensive exploitation of resources. Tula: Tulskii gosudarstvennyi universitet, 2016, p. 333 (in Russian).

4. Vilchinskii V.B., Trofimov A.V., Koreivo A.B., Galaov R.B., Marysyuk V.P. Expediency justification of using hardening stowing mixtures at the Talnakh mines. *Tsvetnye metally*. 2014. N 9, p. 23-28 (in Russian).

5. Golik V.I., Razorenov Yu.I., Stradanchenko S.G., Khasheva Z.M. Principles and economic efficiency of combining the ore mining technologies. *Izvestiya Tomskogo politekhnicheskogo universiteta. Inzhiniring georesursov*. 2015. Vol. 326. N 7, p. 6-14 (in Russian).

6. Progressive methods of enrichment and complex processing of natural and man-made mineral raw materials (Plaksin readings-2014): Materialy mezhdunarodnogo soveshchaniya, 16-19 sentyabrya 2014 g. Almaty: AO "Tsentr nauk o Zemle, metallurgii i obogashcheniya", 2014, p. 624 (in Russian).

7. Krupnik L.A., Shaposhnik Yu.N., Shaposhnik S.N., Nurshaiykova G.T., Tungushbaeva Z.K. Development of the technology of backfilling operations on the basis of the cement-slag binder at Orlovsky mine. *Fiziko-tekhnicheskie problemy razrabotki poleznykh iskopaemykh*. 2017. N 1, p. 84-91 (in Russian).

8. Doifode S.K., Matani A.G. Effective Industrial Waste Utilization Technologies towards Cleaner Environment. *International Journal of Chemical and Physical Sciences*. 2015. Vol. 4. Special Issue, p. 536-540.

9. Golik V., Komashchenko V., Morkun V., Zaalishvili V.B. Enhancement of lost ore production efficiency by usage of canopies. *Metallurgical and Mining Industry*. 2015. Vol. 7. Iss. 4, p. 325-329.

10. Khasheva Z.M., Golik V.I. The ways of recovery in economy of the depressed mining enterprises of the Russian Caucasus. *International Business Management*. 2015. Vol. 9. Iss. 6, p. 1210-1216. DOI: 10.36478/ibm.2015.1210.1216

11. Packey D.J. Multiproduct mine output and the case of mining waste utilization. *Resources Policy*. 2012. Vol. 37. Iss. 1, p. 104-108. DOI: 10.1016/j.resourpol.2011.11.002

12. Franks D.M., Boger D.V., Cote C.M., Mulligan D.R. Sustainable development principles for the disposal of mining and mineral processing wastes. *Resources Policy*. 2011. Vol. 36. Iss. 2, p. 114-122. DOI: 10.1016/j.resourpol.2010.12.001

13. Bian Zhengfu, Miao Xiexing, Shaogang Lei, Chen Shenen, Wang Wenfeng, Struthers Sue. The challenges of reusing mining and mineral-processing wastes. *Science*. 2012. Vol. 337. N 6095, p. 702-703. DOI: 10.1126/science.1224757

14. Golik V., Komaschenko V., Morkun V., Khasheva Z. The effectiveness of combining the stages of ore fields development. *Metallurgical and Mining Industry*. 2015. Vol. 7. Iss. 5, p. 401-405.

15. Golik V.I., Razorenov Yu.I., Ignatov V.N., Khasheva Z.M. The history of Russian Caucasus ore deposit development. *The Social Sciences* (Pakistan). 2016. Vol. 11. Iss. 15, p. 3742-3746. DOI: 10.36478/science.2016.3742.3746

16. Vrancken C., Longhurst P.J., Wagland S.T. Critical review of real-time methods for solid waste characterisation: Informing material recovery and fuel production. *Waste Management*. 2017. Vol. 61, p. 40-57. DOI: 10.1016/j.wasman.2017.01.019

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