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

| Components, kg/m³ | 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 | –  | –  | –  | –  |
| Inert aggregate | 1300 | 1300 | 1300 | 1300 | 1300 | 1300 |
| Water, l/m³ | 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

| Components of the mixture, kg/m³ | Viscosity, sm | Water gain, % | Maximum shear stress, Pa | Strength, MPa, age, s |
|--------------------------------|---------------|---------------|--------------------------|-----------------------|
| Portland cement M-400 | Portland cement M-500 | Wet-ground slag | Sand-gravel aggregate | Ash-slag | Water, l/m³ | 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/m³;
- 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/m³.
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

| Cement | Ash-slag | Screenings | SGA | Water, l/m³ | Maximum shear stress, Pa | Strength in 28 s, MPa |
|--------|----------|------------|-----|-------------|--------------------------|---------------------|
| 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/m³ | Bulk density, kg/m³ | Sieve residue 5 mm, % | Specific surface area, m²/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/m³. The water consumption of 330 l/m³ was insufficient, so the solid stowing had a large value of the maximum shear stress. Increasing the water to 400 l/m³ 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/m³ | Maximum shear stress, Pa | Viscosity, sm | Water sludge coefficient | Density, kg/m³ | Strength, MPa | Age, s |
|---------------------------------|--------------------------|--------------|--------------------------|----------------|--------------|--------|
| Cement                          |                          | Sand         | SGA                     |                |              |        |
| Granulated slag                 |                          |              |                         |                |              |        |
| Ash-slag                        |                          |              |                         |                |              |        |
| SGA                             |                          |              |                         |                |              |        |
| Water                           |                          |              |                         |                |              |        |

| 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 | 1690 | 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, m²/kg |
|----------------------|---------------------------------|----------------------------|
| 1.6                  | 1                               | 0.63 | 0.40 | 0.315 | 0.2 | 0.16 | 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/m³. 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/m³;
- 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%.
Properties of hardening mixtures on a complex binding component with different grinding fineness

| Components of the mixture, kg/m³ | Viscosity, s | Maximum shear stress, Pa | Water gain, % for 1.5 h | Density of slurry, kg/m³ | Strength, MPa age, s |
|----------------------------------|-------------|--------------------------|-------------------------|-------------------------|---------------------|
| Cement                           | Granulated slag | SGA | Water | Without the gravel | SGA | 14 | 28 |
| 80                               | 370          | 1371 | 330 | 17.5 | 25 | 76 | 5 | 1970 | 3.5 | 6.2 |
| 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 |
| 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 |
| 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).

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

| Components of the mixture, kg/m³ | Viscosity, s | Maximum shear stress, Pa | Water gain, % for 1.5 h | Density, kg/m³ | Strength, MPa age, s |
|----------------------------------|-------------|--------------------------|-------------------------|----------------|---------------------|
| Cement                           | Granulated slag | SGA | Water | 1358 | 325 | 20 | 115 | 4.9 | 1925 | 1.5 | 3.1 | 5.8 | 8.5 |
| 80                               | 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 |

The compositions of the mixture on aslag Portland cement binder

| Components of the mixture, kg/m³ | Viscosity, s | Maximum shear stress, Pa | Water gain, % for 1.5 h | Density, kg/m³ | Strength, MPa age, s |
|----------------------------------|-------------|--------------------------|-------------------------|----------------|---------------------|
| Cement                           | Ash-slag | Screenings | SGA | Water | 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 |

Wet processing

| Components of the mixture, kg/m³ | Viscosity, s | Maximum shear stress, Pa | Water gain, % for 1.5 h | Density, kg/m³ | Strength, MPa age, s |
|----------------------------------|-------------|--------------------------|-------------------------|----------------|---------------------|
| Cement                           | Ash-slag | Screenings | SGA | Water | 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 aslag and cement

| Components of the mixture, kg/m³ | Viscosity, s | Maximum shear stress, Pa | Water gain, % for 1.5 h | Density, kg/m³ | Strength, MPa age, s |
|----------------------------------|-------------|--------------------------|-------------------------|----------------|---------------------|
| Cement                           | Ash-slag | Screenings | SGA | Water | 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 |

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

### Compositions of the hardening mixture with mixing

| Components of the mixture, kg/m³ | Viscosity, sm | Maximum shear stress, Pa | Water gain, % for 1.5 h | Density, kg/m³ | Strength, MPa | Age, s |
|---------------------------------|--------------|--------------------------|-------------------------|---------------|---------------|--------|
| Cement                          | Granulated slag | CSS | Water | | | | |
| 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 |

**Intensive mixing in the D-27 disintegrator**

**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/m³;
- 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/m³.

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

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

| The consumption of components, kg/m³ | Shear stress, MPa | Strength in 28 s, MPa |
|-------------------------------------|------------------|-------------------|
| Cement | Slag | Sand | Clay loam | Water | 6 | 0.2 | 10 | 0.6 | 12 | 0.6 |
| 40 | – | 1490 | – | 400 | 6 | 0.2 | 10 | 0.6 | 12 | 0.6 |
| 60 | – | 1470 | – | 400 | 6 | 0.2 | 10 | 0.6 | 12 | 0.6 |
| 80 | – | 1455 | – | 400 | 6 | 0.2 | 10 | 0.6 | 12 | 0.6 |
| 100 | – | 1440 | – | 400 | 6 | 0.2 | 10 | 0.6 | 12 | 0.6 |
| 120 | – | 1423 | – | 400 | 6 | 0.2 | 10 | 0.6 | 12 | 0.6 |
| 150 | – | 1400 | – | 400 | 6 | 0.2 | 10 | 0.6 | 12 | 0.6 |
| 180 | – | 1426 | – | 400 | 6 | 0.2 | 10 | 0.6 | 12 | 0.6 |
| 200 | – | 1360 | – | 400 | 6 | 0.2 | 10 | 0.6 | 12 | 0.6 |
| 140 | – | 941 | 235 | 500 | 48 | 0.8 | 12 | 0.6 | 12 | 0.6 |
| 160 | – | 928 | 231 | 500 | 29 | 0.8 | 12 | 0.6 | 12 | 0.6 |
| 180 | – | 915 | 228 | 500 | 47 | 1 | 12 | 0.6 | 12 | 0.6 |
| 200 | – | 982 | 225 | 500 | 37 | 1 | 12 | 0.6 | 12 | 0.6 |
| 220 | – | 890 | 222 | 500 | 27 | 1.8 | 12 | 0.6 | 12 | 0.6 |
| 140 | – | 524 | 522 | 550 | 30 | 0.8 | 12 | 0.6 | 12 | 0.6 |
| 160 | – | 516 | 514 | 550 | 27 | 0.8 | 12 | 0.6 | 12 | 0.6 |
| 180 | – | 507 | 505 | 550 | 50 | 1 | 12 | 0.6 | 12 | 0.6 |
| 200 | – | 500 | 497 | 550 | 38 | 1.5 | 12 | 0.6 | 12 | 0.6 |
| 140 | – | 660 | 700 | 20 | 0.4 | 12 | 0.6 | 12 | 0.6 |
| 160 | – | 643 | 700 | 10 | 0.4 | 12 | 0.6 | 12 | 0.6 |
| 180 | – | 630 | 700 | 10 | 0.4 | 12 | 0.6 | 12 | 0.6 |
| 200 | – | 610 | 700 | 10 | 0.4 | 12 | 0.6 | 12 | 0.6 |
| 30 | 300 | 1375 | – | 38 | 6 | 0.6 | 12 | 0.6 | 12 | 0.6 |
| 30 | 270 | 1405 | – | 38 | 11.5 | 0.56 | 12 | 0.6 | 12 | 0.6 |
| 30 | 250 | 1425 | – | 38 | 11.5 | 0.56 | 12 | 0.6 | 12 | 0.6 |
| 30 | 220 | 1455 | – | 38 | 11 | 0.46 | 12 | 0.6 | 12 | 0.6 |
| 60 | 250 | 1395 | – | 38 | 12.5 | 0.65 | 12 | 0.6 | 12 | 0.6 |
| 60 | 190 | 455 | – | 38 | 11.5 | 0.53 | 12 | 0.6 | 12 | 0.6 |

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.

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