Replacement of traditional components of the backfill mixture with man-made waste

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Abstract. The formation and storage of man-made waste of water-soluble ores creates a global environmental problem that entails changing landscapes in mining areas and environmental degradation. The involvement of man-made waste in a closed cycle of the production and technological chain makes it possible to reduce the impact of mining and processing on the environment. The use of non-waste (low-waste) technologies, in addition to reducing the environmental burden, allows you to expand the raw material base of the enterprise by replacing the traditional components of the backfill mixture with man-made waste from mining and processing enterprises. The possibility of replacing the traditional, specially extracted aggregate in the backfill mixture with industrial waste of water-soluble ores is experimentally proved. The possibility of creating a cementless backfill mixture is proved. The possibility of replacing the cement binder with magnesium-containing slags of the Chusovsky Metallurgical Plant was confirmed. It was found that the separate activation treatment of the components of the backfill mixture has a positive effect on its rheological properties and increases the strength of the joint mass. The use of lignosulfonate improves the quality of the mixture and the resulting mass. The development of a backfill composite from man-made waste makes it possible to implement the principle of organizing mining production, which provides for the use of intermediate products in cyclic production and excludes the formation of man-made waste of water-soluble ores.

1. Introduction

From previous studies, it follows that the Russian mining industry accounts for about 5% of the world's production of iron ore [1], about 25% of potash ores, and in total Russia produces 9.5% of the world's production of extracted raw materials [2]. However, unlike most countries in Europe and Japan, which provide a high level of environmental safety, the Russian mining industry is at a fairly low level of environmental protection, utilization or processing of man-made waste from the mining and processing and metallurgical sectors and their use in subsequent production [2, 3].

Every year, the content of the useful component in the extracted ore decreases, which leads to more waste generation after its processing. The accumulation of industrial waste is one of the forms of human impact on the ecosystem, which leads to various qualitative or quantitative changes in its elements [4].

When receiving 1 ton of potash fertilizers, up to 30 tons of water-soluble tailings are formed, for the removal and storage of which an average of 5 to 8% of the cost of the products produced is spent.
But if we recognize that the lifetime of waste dumps is unlimited, then the multiplicative damage from the placement and storage of man-made waste may exceed the value of the extracted product. To date, no more than 10% of the extracted rocks from overburden and sinking operations and about 20% of water-soluble industrial enrichment waste are used in cyclic production. According to the Ministry of Natural Resources and Ecology, more than 45 billion tons of waste from mining and processing production of various hazard classes have been stored on the territory of Russia to date. In Russia, the level of pollution from man-made waste is increasing every year. Over the past twenty years, the annual growth of man-made massifs with waste rock from sinking and overburden operations has increased by 30% and amounts to 210 million m³/year, and waste from processing plants amounts to 140 million m³/year [5]. All these volumes pollute the environment, remove fertile land from circulation, occupying thousands of hectares of agricultural land.

2. Experience in the use of man-made waste in backfill mixtures

The idea of using waste from processing and metallurgical processing to replace an aggregate in the creation of a backfill composite is not new [6-8]. The use of water-soluble waste generated as a result of enrichment to create composite mixtures will allow the utilization of man-made waste, which will significantly reduce the impact of the mining sector on the ecosystem of the region [9]. From the analysis of the world practice of mineral extraction, it follows that 35% of mining enterprises prefer systems with artificial maintenance of the stope, namely, systems with a hardening backfill. The development of a geotechnological deposit with a backfill improves the qualitative and quantitative indicators of extraction [10], increases safety at mining sites and mineral extraction in general [11], reduces the risks of man-made accidents at mining enterprises [6, 8]. Man-made disasters at mining enterprises: sinkholes; mountain impacts and man-made earthquakes, often accompanied by seismic activity and vibration fluctuations. The influence of vibration vibrations on underground workings and surface structures has been widely discussed in previous studies [12-16].

When creating a backfill composite, cement or its derivatives are used as a binder, and specially extracted materials are used as an aggregate: sand, gravel, crushed stone. Man-made waste from mining and processing industries is widely used in the mining sector around the world, with the total annual volume of extraction of minerals in these countries is about 64 million tons. The share of using man-made waste from the mining sector to replace a specially extracted aggregate is distributed as follows: 67% - waste from processing plants, 25% - waste rock from overburden and sinking operations, 7% - sands and slags from metallurgical processing or thermal power plants [17].

In the waste of processing plants and metallurgical plants, although not in a significant amount, there are useful components that can be extracted during repeated deep processing (Table 1). Often, man-made waste from the mining and processing and metallurgical sectors contains harmful impurities. All this significantly limits the possibility of using man-made waste in cyclic production. The idea of using industrial waste of water-soluble ores in the preparation of composite material used for backfilling of the worked-out space is not sufficiently new [18-23]. Previously conducted studies of the activation treatment of industrial waste from polymetallic ore processing plants have shown positive results [7, 8, 17, 24]. But the use of water-soluble industrial waste from processing plants as an aggregate was carried out without additional activation processing.

In addition, the mixtures used for mining operations in the extraction of mineral raw materials differ from mixtures, mortars and concretes intended for civil construction by an increased amount of water. An increased ratio of water to the solid component in the backfill composites is necessary to improve its transport capacity to the backfill site and spreadability in the chamber. The increased water content leads to a decrease in the strength characteristics of the created artificial mass [24].

In this regard, the purpose of this study was to create a composite material based on water-soluble industrial waste of the galurgical method of enrichment with specified rheological properties and intended for the formation of an artificial mass with increased strength characteristics.
Table 1. Chemical composition of manmade enrichment waste of water-soluble ore.

| Enrichment waste | Components | KCl | NaCl | MgCl₂ | CaSO₄ | Insoluble residue | Br⁻ | H₂O₅剩余 |
|------------------|------------|-----|------|-------|-------|-------------------|-----|-----------|
| Halurgic         | Stale      | 3.35| 92.66| 0.07  | 1.91  | 1.9               | 0.03| 0.08      |
| Current          | 1.91       | 94.3| 0.07 | 1.914 | 1.7   | 0.026             | 0.08|
| Flotation        | Stale      | 9.96| 82.64| 1.1   | 4.488 | 1.7              | 0.032| 0.08      |
| Current          | 4.88       | 87.78| 1.1 | 4.331 | 1.8   | 0.029             | 0.08|

As an aggregate, man-made water-soluble waste from a processing plant that has undergone additional activation treatment is used. The chemical and granulometric compositions of waste from the water-soluble ore processing plant are given in Tables 1 and 2.

Table 2. Granulometric composition of manmade enrichment waste of water-soluble ore.

| Particle size allocation, mm | Average |
|-----------------------------|---------|
| +7                          | 7.4     |
| 7-5                         | 7.3     |
| 5-3                         | 17      |
| 3-2                         | 16.3    |
| 2-1                         | 20.9    |
| 1-0.5                       | 19.5    |
| 0.5-0.25                    | 8.6     |
| -0.25                       | 3.0     |

Taking into account the previously accumulated experience in the mining industry, it is necessary to take into account that when creating a composite for the developed space on the basis of man-made waste of water-soluble ores, the following materials are used as binders: cement, lime, granulated blast furnace slags of metallurgical processing, ash and slag waste from CHPP and GRES, additives from gypsum and calcium chloride. In addition, the fundamental material for the preparation of a hardening composite can be: bischofite, magnesian cement, caustic magnesite, expanded clay.

Research work carried out earlier in the field of creating hardening backfill mixtures based on water-soluble ore waste demonstrated the advantage of magnesia binders [9, 22].

3. Research of the fill mass created based on man-made waste

Previous studies have shown that salt solutions are most effective as a recluse, since the rate of hardening and strength characteristics of the mass increase dramatically [17-19]. An additional advantage of magnesia binders is the ability to form sufficiently strong bonds in small quantities for a large mass of aggregate, in this case, man-made waste of water-soluble ores [18-20]. For industrial production, it is not necessary to use specially prepared magnesian cement or caustic magnesite as a binder. To reduce the cost of stowing operations, it is possible to use waste from magnesium and soda production or magnesium-containing slags from metallurgical plants, which is of interest given the significant volume of stowing operations [18, 22].

The reduced joint-ability can be compensated using cement or an activating additive. During the experiments in this work, magnesium-containing slags of the Chusovsky Metallurgical Plant were used.

All experiments were carried out in accordance with the guidelines and instructions for quality control of backfill mixtures [25].

Magnesia slags and industrial waste from the enrichment of water-soluble ores were added to the backfill mixture in the proportions of 25% and 51% of the total volume, respectively. At the same time, the components were separately activated in the DESI-11 disintegrator by grinding to a class content of less than 0.071 mm of at least 68 – 72% and 85 – 91% of each component, respectively. To increase the service life of crushers, it is proposed to use new technologies for their manufacture and diagnostics of wear [26].

The mobility, delamination, and spreadability of the backfill composite were studied using the standard StroiTSNIL method based on the depth of the cone sediment and on a viscometer.
Solidification of the samples took place under the conditions provided for by the procedure \( T=20\pm 2 \, ^\circ\text{C}; \, W=95\pm 5\% \) and their compression test was performed after the specified time provided for by the procedure: 7; 28; 60 and 90 days \[25\].

Tests of the first composition showed unsatisfactory results, which was reflected in the low strength characteristics of the samples and the low mobility of the composite (composition No. 1 in Table 3).

In order to increase the hydraulic activity, the magnesia slag was treated to a fineness of at least 88-92\% and less than 0.071 mm. The size of the waste from the enrichment of water-soluble ores was left unchanged. To determine the size of the slag grains and enrichment wastes, the express method was used tested in \[27\]. When testing the samples for uniaxial compression, there was a noticeable increase in the indicators. But at the same time, it must be stated that the rheological properties of the backfill mixture did not meet the indicators of transportability to the place of fill mass (composition No. 2 in Table 3).

### Table 3 Test results of backfill mixtures and samples after solidification

| № | Components | Enrichment waste | Slump compression, cm | Flowability, mm | Ultimate uniaxial compression strength, MPa | Duration of mixture hardening, days |
|---|---|---|---|---|---|---|
| 1 | 25.0 | 68 – 72 | 51.0 | 85 – 91 | 24.0 | 11 | 0.2 | 1.5 | 1.9 | 2.2 |
| 2 | 25.0 | 85 – 91 | 51.0 | 85 – 91 | 24.0 | 9 | 95 | 0.15 | 1.6 | 2.2 | 2.5 |
| 3 | 25.0 | 85 – 91 | 51.0 | 68 – 72 | 24.0 | 14 | 120 | 0.1 | 1.2 | 1.7 | 1.8 |
| 4 | 25.0 | 85 – 91 | 51.0 | 85 – 91 | 23.25 | 17 | 165 | 0.25 | 2.0 | 2.75 | 3.1 |

To improve the rheological properties and increase the spreadability of the backfill mixture, we tried to reduce the fraction of less than 0.071 mm in the industrial waste from the enrichment of water-soluble ores. This experiment led to a drop in the strength of the samples during the uniaxial compression test (composition No. 3 in Table 3).

An increase in the water-solid ratio to improve the rheological properties is impractical, due to a sharp drop in the strength characteristics of the backfill mass and an increase in the volume of drainage.

Earlier studies have shown the prospects of using chemical additives in the creation of materials with stronger structural bonds \[28\], which makes it possible to increase the strength characteristics of the created artificial mass \[17, 22\]. The activating additives that can not only increase the strength characteristics of the backfill mass, but also increase the transportability of the backfill mixture include lignosulfonates \[18, 29\], obtained by processing spent sulfite and bisulfite lye.

The use of lignosulfonates made it possible to obtain a backfill mass with increased strength with rheological characteristics that meet the requirements of transportability (No. 4 in Table 2). The improved rheological properties of the backfill mixtures make it possible to completely abandon conveyor transport \[30\] in favor of pipeline transport.

The study of the kinetics of strength gain over time, depending on the components used and the effect of mechanical and chemical activation on them, is clearly demonstrated in Figure 1.
When creating an artificial mass based on man-made waste, it is necessary to consider the long-term impact of the backfill components on the joint mass and rather strictly approach their application. All the processes that can occur in an artificial mass after the solidification of the backfill mixture is almost impossible to predict and simulate. The methods and methods of controlling the joint mass are considered quite fully and completely in [31, 32].

The use of man-made waste in the preparation of composite material intended to maintain the stope, without additional processing, contradicts the economic feasibility and environmental safety. Technologies for extracting useful components from man-made waste have been developed [33].

With the development of science, technology and technology, the quality indicators of enrichment are improving, which is confirmed by the analysis of the chemical composition of the tailings taken from the tailings storage facilities (before 2000) and directly from the enrichment production line (Table 1) at the Uralkali plant.

Therefore, for backfill operations, without additional processing, it is possible to use the current tailings of the galurgical method of enrichment. When using the stale tailings of the galurgic method of tailings of the flotation method of enrichment, it is necessary to make their additional enrichment. Additional enrichment can be carried out at the processing plant facilities that were released as a result of the reduction in the company's production volumes due to the decommissioning of BKRP-1 Uralkali.

4. Conclusion

The use of cementless technology to create an artificial mass based on water-soluble man-made waste allows you to develop a fill mass with the necessary strength characteristics. The use of waste from mining and industrial production to create a composite material leads to their disposal, eliminates the use of specially extracted raw materials for the components of the mixture, which reduces the cost of mining operations, and as a result reduces the cost of the extracted ore. The development of a backfill mixture from man-made waste makes it possible to implement the principle of organizing mining production, which provides for the use of intermediate products in cyclic production and excludes the formation of man-made waste of water-soluble ores.

The creation of non-waste mining production with the use of intermediate products in cyclic production allows us to preserve the ecology of the region. The use of man-made waste of water-soluble ores in cyclic production will subsequently lead to a multiplicative economic effect, determined by the sum of the values of the prevented environmental damage, the costs of storage and storage, the costs of disposal and environmental deductions.
The use of man-made waste of water-soluble ores will have a positive economic effect without their re-processing and production. At the same time, the involvement of water-soluble ores in the processing of man-made waste creates prerequisites for the creation of a new material and raw material base of the mining complex and eliminates the costs of exploration and development of new deposits.

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