Reducing the environmental impact of mining production through the use of man-made waste

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Abstract. The admissibility of replacing traditional cement, used as a binder with magnesium-containing man-made waste in the preparation of a construction and fill mixture is justified. The possibility of replacing the traditional specially mined aggregate in construction and fill mixtures is proved. The results of testing samples after cementing and a construction-fill mixture prepared on the basis of man-made waste are presented. The positive effect of mechanical activation of the backfill mixture components on its rheological properties and strength characteristics of the fill mass is studied. The use of lignosulfonate as an additive was confirmed to improve the binding and rheological properties of the backfill mixture. The involvement of man-made waste in the closed cycle of the main and auxiliary production reduces the volume of man-made massifs, which significantly reduces the impact of mining production on the environment.

1. Referat

Every year there is an increase in the volume of consumption of georesources, which leads to an intensification of their extraction from the subsurface. This causes an increase in the accumulation of man-made waste stored on the surface, which has a significant impact on the environment. The term of existence of man-made massifs is unlimited, therefore, the environmental damage can subsequently significantly exceed the economic benefit from the extracted resources.

At the same time, it is necessary to consider that in man-made waste, useful components remain in significant volumes and the waste itself can be raw materials for secondary use. In this regard, it is necessary to introduce the concept of non-waste (low-waste) production.

The creation of closed-loop production utilizing secondary products is a paradigm for the development of mineral resources. This will significantly reduce the impact on the environment. Industrial waste is perceived as a “by-product” of mining production. They must be qualified as a secondary (intermediate) product used for subsequent use or processing.

The main direction of using industrial waste can be the replacement of traditional, specially extracted aggregate when creating a backfill or construction mixture.

The re-use of man-made waste in a non-waste technological chain, in addition to their disposal, significantly reduces the risk of environmental impact of mining and processing production.

Before using man-made waste in construction and backfill mixes, it is necessary to consider that they have useful components in their composition, although not in a significant amount. In this regard, it should be noted that before using man-made waste in mixtures, it is necessary to extract useful components by deep processing.

When choosing the compositions of building and laying mixes, it is necessary to consider their features. It should be noted that the mixtures used to produce laying works in the extraction of minerals have a higher water-solid ratio in comparison with the solutions used in construction.

The use of man-made waste is hindered by the presence of harmful components in the waste that have a negative impact on monolithic structures, or the artificial mass being created. Neutralization of
the negative impact of the components remaining in man-made waste is possible as a result of their deep processing. This will not only neutralize the impact of harmful components, but also introduce resource-renewable technologies.

The maximum ecological and economic effect of the use of man-made waste in construction and backfill mixtures can be achieved only after their deep processing and additional extraction of useful components and neutralization of the negative effect of the remaining ones. At the same time, the involvement of mining and processing industries in deep processing 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.

2. Introduction

Russia is one of the world leaders in the extraction of mineral resources and the production of products from extracted raw materials. Russia accounts for up to 5% of the world's iron ore production, about 25% of potash raw materials, and in total, Russia produces about 10% of the total world production of the mining industry [1].

But at the same time, it should be noted that Russia lags far behind European countries and Japan in terms of ensuring environmental safety [2]. The Russian mining and processing industry is not at a sufficiently high level of ensuring environmental safety, processing and disposal of man-made waste from mining and processing industries and their use in the further technological scheme or production of products that are not related to the main activity of the mining and processing enterprise [3].

Every year, the useful content of recoverable reserves decreases, which leads to an increase in processing waste [4]. Developments go to great depths, which leads to an increase in the volume of rocks from overburden and tunneling operations. All these industrial wastes are stored on the surface, forming huge massifs [5]. Waste storage in industrial massifs is a form of anthropogenic impact on the environment, which causes qualitative and quantitative changes in its subjects [6].

About 30 tons of water-soluble industrial waste is generated during the production of 1 ton of potash fertilizers. Approximately 5 - 8% of the production cost is spent on warehousing, storage, construction of storage facilities for man-made waste, environmental deductions, etc. [7]. At the same time, it should be noted that the lifetime of man-made massifs is unlimited, therefore, the multiplicative damage from their placement will subsequently exceed the value of the extracted raw materials [8].

Until now, when reused, up to 10% of the extracted rocks from sinking and overburden operations are disposed of [9] and no more than 20% of water-soluble industrial waste [10]. According to the Ministry of Natural Resources and Ecology, about 45 billion tons of man-made waste from the mining and processing sector of various hazard classes are stored in industrial massifs in Russia [11].

All over the world, including Russia, there is an annual increase in the level of pollution of the environment by man-made waste. Since the beginning of the XXI century, the annual volume of expansion of man-made massifs with waste rock increases by 30% and amounts to 210 million m³ / year, and waste from processing production amounts to 140 million m³ / year [12]. The formed industrial massifs disrupt the ecological balance, withdraw fertile agricultural land from circulation [13].

Often, it is proposed to preserve the pristine nature and mineral diversity of the Earth by transferring mining production to cosmic bodies [14]. But the lack of technical possibilities for implementation [15] and unresolved legal issues [16] postpone the implementation of this idea for the distant future.

3. The use of man-made waste in construction and backfill mixes

The development of the society leads to an increase in the extraction of mineral resources and the construction of both industrial facilities [17] and civil buildings [18]. About 35% of enterprises in the mining sector use geotechnology with the use of developed stopes [19] and their share is constantly increasing.
In the production of construction and backfill mixes, cement or its derivatives are used as a binder, and specially extracted materials are used as an inert component: sand, gravel, crushed stone. Considering the increase in the volume of construction of buildings and structures and the fairly active introduction of geotechnology with a backfill mass, the issue of replacing the components of the mixture with cheaper and more affordable ingredients is acute. Therefore, the use of man-made waste from mining and processing production is seen as a good option [20].

The idea of using man-made waste to replace the traditional, specially extracted aggregate when creating a backfill mixture is not new [21]. At the same time, it should be taken into account that the creation of building mixes has similar technological aspects to the production and design of backfill mixes [22]. The use of waste water-soluble ores formed after their enrichment as an aggregate in construction and backfill mixtures will allow the introduction of waste-free (low-waste) production [23]. The re-use of man-made waste in a non-waste technological chain, in addition to their disposal, significantly reduces the risk of environmental impact of mining and processing production [24].

Before using man-made waste in construction and backfill mixes, it is necessary to take into account that they have useful components in their composition, although not in significant quantities (Table 1). In this regard, it should be noted that before using man-made waste in mixtures, it is necessary to extract useful components by deep processing.

In addition, the use of man-made waste in construction and backfill mixes is hindered by the presence of harmful components in the waste that have a negative effect (softening, swelling, increasing porosity, etc.) on monolithic structures or the artificial mass created after the mixture solidifies [25]. Similarly, the harmful components of man-made waste can remain in a conditional equilibrium state for a long time [26]. But after exposure to the environment or when interacting with other components, they pass into a mobile state, are washed out of structures or artificial massifs, which leads to a violation of the ecological balance [27].

Currently, technologies for deep processing of man-made waste have been developed, which allow for additional extraction of useful components [28]. The technology of deep processing will also allow to neutralize the negative impact of harmful components on the created structures or mass and the environment [29]. This technology creates prerequisites for the introduction of resource-renewable technologies, contributes to the increase in the mineral resource base of the mining enterprise and increases its working life [30].

The most effective technology of deep processing at the present time is the mechanochemical technology. This technology combines chemical irrigation of industrial waste and their mechanical treatment in a disintegrator [31].

The idea of using water-soluble ore waste in mixtures to replace an aggregate is not new. The replacement of the traditional aggregate with the waste of water-soluble ores was previously carried out without their additional activation treatment [32]. At the same time, it should be noted that earlier studies have shown a positive effect of the activation treatment of industrial waste [33].

It should be noted that the mixtures used to produce laying works in the extraction of minerals have a higher water-solid ratio in comparison with the solutions used in construction.

The increased volume of water in the backfill mixtures is necessary in order to improve its transportability from the place of production to the place of laying and spreadability in the waste chamber. Strength and transportability have opposite dependencies on the amount of liquid in the mixture.

Since the main cost in the construction and backfill mix is cement, the search for its replacement always remains relevant. Earlier experiments have shown the possibility of using metallurgical slags after activation treatment as a binder [34].

Research work carried out earlier in the field in the creation of mixtures using water-soluble ore waste as an aggregate has demonstrated the advantage of binders containing magnesium.
The rheological characteristics for the backfill mixture were carried out according to the instructions. Therefore, the aim of this research work is to develop a cementless construction-laying mixture based on waste water-soluble ores with specified rheological properties and intended for the formation of a monolith or artificial massif with specified strength characteristics.

When developing the composition of the mixture, waste from water-soluble ores of Uralkali was used as an aggregate, and slags from the Chusovsky Metallurgical Combine were used as a binder. All components were applied after activation treatment. The chemical and granulometric compositions of waste from the water-soluble ore processing plant are given in Tables 1 and 2.

**Table 1. Chemical composition of industrial waste from water-soluble ore dressing.**

| Waste enrichment | Components | KCl | NaCl | MgCl₂ | CaSO₄ | Insoluble residue | Br | H₂O₇cryst |
|------------------|------------|-----|------|-------|-------|------------------|----|------------|
| 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       |

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**Table 2. Granulometric composition of industrial waste from water-soluble ore dressing.**

| Particle size, mm | Waste | 7-5 | 5-3 | 3-2 | 2-1 | 1-0.5 | 0.5-0.25 | 0.25 | Average size |
|-------------------|-------|-----|-----|-----|-----|-------|---------|------|-------------|
|                   |       | 7.4 | 7.3 | 17  | 16.3| 20.9  | 19.5    | 8.6  | 3.0         | 2.54         |

4. **Creation of an artificial mass based on man-made waste of water-soluble ores**

As can be seen from Table 1, industrial waste of water-soluble ores consists of 94-98% of salts, therefore, it is easily soluble in water. To exclude their dissolution in the construction-laying mixtures, saturated salt solutions were used as a recluse. Previous studies have proven the effectiveness of saturated solutions.

Magnesia binders, including magnesia cement, are able to form sufficiently strong crystal bonds in small quantities and combine a large amount of aggregate into a monolith. In industrial applications, it is not necessary to use derivatives of magnesium-containing cement. In order to reduce the cost of the construction and backfill mixture, magnesia cement or caustic magnesite can be replaced with slags that have an increased magnesium content in their composition. Due to the large volume of construction and monolithic works on construction sites and laying works at mining enterprises, the use of magnesium-containing slags as a substitute for binder is very promising.

It is possible to increase the ability of slags to solidification by adding a small amount of cement or an activating additive to the mixture. Earlier studies of the mechanical activation treatment of the components of the backfill mixture showed positive results [35]. In this regard, in this study, the activation treatment of slags and waste of water-soluble ores in disintegrators was carried out.

When conducting experimental studies, they were based on methodological guidelines and instructions.

Waste from the processing of water-soluble ores and magnesia slags in the construction-backfill mixture were mixed in the proportion of 51% and 25% of the total volume of the composite, respectively. Before mixing, separate activation treatment of the components of the construction-laying mixture was performed in the DESI-11 disintegrator. In the activation unit, the magnesium-containing slags were crushed to a class content of less than 0.071 mm of at least 68-72%, and the waste of water-soluble ores—at least 88-92%.

The rheological properties of the mixture are important for quenching operations, since it often has to be transported over long distances from the production site to the place of laying in the stopes. Therefore, the rheological characteristics for the backfill mixture were carried out according to the
established standard methods: the depth of shrinkage of the cone; the spreadability of the mixture on the viscometer. The samples were solidified under the conditions specified in the procedure (T=20±2°C; W=95±5%) and their compression test was performed after the specified time specified in the procedure: 7; 28; 60 and 90 days. Samples for uniaxial compression were tested on a PI-2000-A press. The results of the experiments are listed in Table 3.

Table 3. Test results of backfill mixtures.

| No | Magnesian slag | Enrichment waste of water-soluble ores | Lingosulfanate-% of solid | Water, mass-% | Spreading, mm | Cone draft, cm | Duration of hardening, days |
|----|----------------|----------------------------------------|---------------------------|---------------|---------------|----------------|--------------------------|
| 1  | 25.0           | 68 – 72                                | 51.0                      | 88 – 92       | -             | 24.0           | 105                       | 0.2                      |
| 2  | 25.0           | 88 – 92                                | 51.0                      | 88 – 92       | -             | 24.0           | 95                        | 0.15                     |
| 3  | 25.0           | 88 – 92                                | 51.0                      | 68 – 72       | -             | 24.0           | 120                       | 0.1                      |
| 4  | 25.0           | 88 – 92                                | 51.0                      | 88 – 92       | 1             | 23.25          | 165                       | 0.25                     |

From the comparative analysis, it follows that the first composition of the construction-laying mixture demonstrated low strength characteristics when tested for uniaxial compression after solidification and its low mobility (composition No. 1 in Table 3).

To increase the hydraulic activity, the binder, in our case magnesia slag, was machined in a disintegrator to a fineness of 88-92% of the class less than 0.071 mm. The size of the aggregate was left unchanged. Testing of the samples after solidification demonstrated a significant improvement in strength parameters. But at the same time, the rheological characteristics were unsatisfactory, which indicates poor transportability of such a mixture (composition No. 2 in Table 3).

To increase the spreadability of the construction-backfill mixture and, in general, its rheological properties, the fraction fraction of less than 0.071 mm of the aggregate was reduced. Testing of samples after solidification for uniaxial compression showed a sharp drop in strength characteristics (composition No. 3 in Table 3).

The increase in the water-solid ratio, which makes it possible to change the rheologic characteristics of the mixture, was immediately abandoned, due to the inexpediency of this experiment. Previous studies have shown that the addition of water to the mixture reduces the strength of the monolith, structures and the mass and increases the volume of drainage.

From the analysis of previous studies, it was concluded that the use of activating additives makes it possible to create with stronger structural-crystal bonds [36], which significantly increases the strength characteristics of monoliths and artificial massifs [37]. In addition, chemical additives have positive changes on the rheological characteristics of the created mixture. Such additives include lignosulfanate-waste from the pulp and paper industry obtained by processing spent sulfite and bisulfite liquors [38, 39].

The introduction of lignosulfanate into the composition of the construction-laying mixture allowed us to obtain samples with increased strength characteristics. At the same time, the rheological characteristics of this mixture fully meet the requirements of its transportability through pipelines (composition No. 4 in Table 3).

When creating monolithic structures in construction and artificial massifs in the mining industry, it is necessary to strictly take into account the long-term influence of the components of the mixture and selectively approach their choice. The processes that occur in monolithic structures and in the mass after their complete solidification are difficult to predict and model. Methods and methods of control
of monolithic structures and artificial massifs after their solidification are sufficiently fully investigated in the works.

The use of man-made waste in the preparation of construction and backfill mixture without additional, deep processing is contrary to environmental safety and economic feasibility. Resource-renewable technologies for deep processing of man-made waste have been developed, which make it possible to additionally extract useful components from them.

With the introduction of innovative enrichment technologies, there is an improvement in qualitative and quantitative indicators, which is proved by the analysis of the composition of the tailings of the processing plant (Table 1).

Therefore, it is recommended to use the current tailings of the galurgical method of enrichment as part of the construction-backfill mixture without additional processing. When using the stale tailings of the galurgical method of enrichment and the 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 production volumes of the enterprise due to the decommissioning of "Uralkali" Berezniki mines.

5. Conclusions
Replacing the traditional cement binder with magnesium-containing slags in the construction-laying mixture allows us to develop a composition that meets the strength characteristics of artificial massifs or building structures that do not carry a high load. The use of man-made waste in the construction-laying mixture is possible after their mechanical activation treatment in disintegrators, which increases the strength characteristics of structures and artificial massifs.

The maximum ecological and economic effect of the use of man-made waste in construction and backfill mixes can be achieved only after their deep processing and additional extraction of useful components and neutralization of the negative effect of the remaining ones. At the same time, the involvement in deep processing of waste from mining and processing industries 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.

The involvement of man-made waste in the closed cycle of the main and auxiliary production reduces the volume of man-made massifs, which significantly reduces the impact of mining production on the environment.

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