KEY FACTORS IN THE IMPLEMENTATION OF PROJECTS FOR BACKFILLING OPEN TECHNOGENIC CAVITIES IN THE MINING INDUSTRY

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Today, in the era of rapid technological progress of mankind, mineral resource mining is of great importance as it is the fundamental basis for the development of space and aviation technologies, medicine, electronics, IT-sphere, infrastructure construction, as well as the creation of new goods and services. Colossal volumes of mineral resource mining on the planet create a powerful anthropogenic impact on the natural environment, especially the upper layer of the earth's surface, changing natural landscapes to technogenic ones [1, p. 151; 2, p. 1]. A particularly complicated technogenic-environmental situation arises in the case of complex open and underground mining of minerals, when, in addition to quarrying and accumulated mining waste, uncontrolled processes of the earth's surface shear due to the impact of underground mining operations may occur.

In open-pit mining, the earth's surface at the site of quarries is extremely rarely restored. In the case of sufficient volumes of waste rock, the quarry cavities can be filled for the construction direction of reclamation. However, other directions of reclamation are most often chosen, such as the creation of artificial water bodies for recreation or fishery, forest plantations and creation of terraces on the slopes of quarries, as well as the construction of various cultural and sports facilities in the mined-out spaces of quarries. A similar situation is observed in the formation of deep failure zones due to the influence of underground mining. These processes are usually uncontrolled and threaten not only soils and natural ecosystems, but also the safety of the life of the population that may live in the zone influenced by underground mining.

To minimize the negative impact of mining processes on the environment, a number of "green technologies" are currently used, including backfilling of mined-out space of mines, recycling of industrial waste, development of alternative energy sources, use of low-waste technologies, etc. [3, p. 1; 4, p. 1; 5, p. 765].

However, the solution to the problems of restoring the earth's surface damaged by open deep technogenic cavities from mining processes today is

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poorly studied and requires more attention from the scientific community. Usually, to fill the mined-out spaces of quarry and failure cavities, backfilling with dump waste rock is used. Given the complex of disadvantages of this method, we propose a new approach to backfilling of surface cavities – the transition from a loose medium to a monolithic state of the backfill mass. This approach is examined on the example of a large iron ore basin in Ukraine.

Ukraine is among the top 20 countries in the world in terms of the extent of land used for mining industry, which is estimated at about 600 km^2 [6, p. 1]. Most of the land has been alienated for mining facilities in Dnipropetrovsk Oblast, namely the Kryvyi Rih Iron-ore Basin, where large-scale open-pit and underground mining is conducted. About 160-170 million tons of iron ores are mined annually in 9 large quarries and 8 mines [7, p. 1]. As part of this research, a comprehensive geospatial study of existing surface technogenic cavities was conducted and it has been determined that in addition to active quarries, there are 3 inactive and unreclaimed quarries in the region, as well as 15 large mine failure zones, over which the area of the damaged earth's surface is about 200 hectares.

Significant volumes of mining-metallurgical waste have been accumulated around the city of Kryvyi Rih, estimated at 10.7 billion tons, namely: waste rock dumps of quarries and mines, tailings dumps, dumps of various types of metallurgical slags. In addition, at a distance of 30-40 km from the city in the eastern and south-eastern direction, there is a limestone quarry and an ash-sludge dump. If to look at the diversity of industrial waste from the point of view of the mineral raw material base of cementitious and inert backfill materials, the region has favorable conditions for the introduction of monolithic cavity backfill technologies. An analysis of the volumes and directions of waste use shows that the greatest difficulty in utilization is observed with finely dispersed iron ore tailings, which, by the way, are a source of atmosphere and adjacent area pollution due to intense dusting. Tailings are the main component in the technology of paste backfilling of mined-out spaces of mines, to which a small amount of cementitious material and water is added.

Taking into account the presence in the Kryvyi Rih region of inactive technogenic cavities (quarries and failures) and the necessary backfill material reserves, a new concept of restoring the earth's surface based on cemented paste backfilling in the western part of Kryvyi Rih is being discussed, where today there are optimal conditions for its use. In order to form a sustainable, efficient, and environmentally safe backfill mass in quarry cavities, a number of key factors should be taken into account when designing the technology. Schematization of the concept and key factors of its implementation are illustrated in Figure 1.

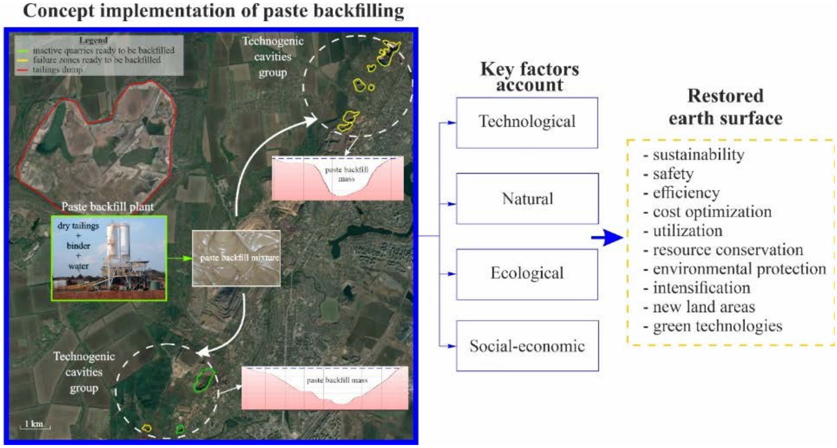

Figure 1. The concept of cemented paste backfilling and key factors for its implementation (image of paste backfill plant taken from https://cmqengineering.com)

Such complex projects as backfilling mined-out space in quarries or failure zones using monolithic methods require in-depth knowledge in the field of mining, mining geomechanics, materials science, engineering geology, hydrogeology, ecology, and construction technologies. The essence of technological, natural, ecological, and social-economic factors is given in Table 1.

Next, a brief description of the importance of key factors is provided. The volume and geometry of technogenic cavities are of great importance, which determines the required amount of backfill materials for complete backfilling and the specific peculiarities of the technology for forming the backfill mass. The prediction of hydrogeological conditions is of particular importance for backfilling quarry cavities. The quarries shown in Figure 1 are currently in absolutely dry conditions, which is probably due to the influence of the formed depression funnel around a large quarry and an iron ore mine. Therefore, it is necessary to predict for the long term whether the quarry bowl could be watered as a result of a theoretically possible outage of the drainage system. This is essential in order to take into account the possible impact of water on the backfill mass stability and the need to seal the mass bottom. Probably the most important key factor is the choice of the component composition of the paste backfill mixture, namely the type and dosage of the cementitious material, as well as the solid part content (tailings and cementitious material) in the backfill mixture. The rational component composition of the paste backfill mixture should contribute to minimizing its hardening rate, its best rheological properties for pipeline transportation at a distance of 4-5 km (viscosity, shear stress), the best deformation and strength properties of the backfill mass, its homogeneity, water resistance and durability in hot periods. The component composition of the backfill mixture will largely determine the list of necessary technological equipment of the backfill complex. An important aspect that will influence the economic costs of the paste backfilling process is the availability of a technological operation for crushing cementitious materials, for example, such as blast furnace slag or limestone screenings. Therefore, the ideal condition would be such a cementitious material or a combination of cementitious materials that does not require a complex crushing cycle and minimizes the content of expensive cement. The component composition of the backfill mixture as it hardens should provide sufficient strength and geomechanical reliability of the backfill mass surface, be characterized by the absence of subsidence values critical for the construction of certain categories of infrastructure projects on the restored surface.

Table 1

Key factors in the implementation of the concept of disturbed earth's surface restoration based on paste backfilling

Class of factors	List of main key factors
Technological	− Volume and geometry of technogenic cavities − Prediction of hydrogeological conditions − Backfill mixture quality and properties − Technological equipment simplicity − Rock mass surface geotechnical stability
Natural	− Climate factors − Topography of the area
Ecological	− No environmental pollution during backfilling − Maximum utilization of waste during backfilling
Social-economic	− Value of land area at the quarry site − Integration of land area into the regional economy − Industrial symbiosis to cover costs − Safety of population and infrastructure

When performing paste backfilling operations of surface technogenic cavities, the influence of climatic conditions, namely temperature and atmospheric precipitation, is inevitable. The temperature regime of the Kryvyi Rih region makes it possible to determine that the ideal period for conducting paste backfilling operations is April-October, which is determined by the necessary conditions for hardening the backfill mixture and the gaining of strength by the future mass. In the period from November to March, it is recommended to backfill with dump waste rocks to prevent a reduction in reclamation rates and to avoid the influence of climatic conditions. Therefore, it is expedient to form a combined backfill mass. The organization of backfill operations during the warm season should be closely related to the atmospheric precipitation forecast and be characterized by certain specifics, namely the need for hardening of the mass before precipitation occurs. The topography of the area will determine the reduction or increase in energy consumption for transporting the backfill mixture. In the analyzed case (Fig. 1), from the backfill complex to the identified cavities, the terrain relief in absolute elevations decreases, which is a positive aspect during transportation, since the mixture moves from top to bottom.

Technological operations on preparation, transportation and formation of paste backfill mass should be environmentally friendly. Pipeline transportation provides maximum environmental friendliness and mobility of the backfill mixture delivery. In the event of contact of the formed backfill mass with groundwater, the products of their interaction should not be toxic. The maximum utilization of waste in the composition of the backfill mixture is one of the best environmental indicators. For example, in addition to beneficiation tailings, fly ash is also utilized as part of the cementitious material.

At the stage of designing the implementation of paste backfilling operations, a predictive assessment of the value of the restored land area at the quarry site should be made according to an approved methodology, which will provide an estimate of the profit from the sale or lease of land. It is also necessary to develop mechanisms and plans for integrating the restored land area into the economy of the Kryvyi Rih region prior to backfilling operations. The restored earth’s surface should be used as efficiently and rationally as possible for the development of the city’s infrastructure.

The principles of industrial symbiosis between stakeholders, such as enterprises and government authorities, can be used to ensure a fair distribution of investment funds for projects of paste backfilling of open technogenic cavities. The implementation of paste backfill technology for mine failure zones will be of great social importance, as it will stop or attenuate further earth’s surface deformations and the probability of caving, which is important for the safety of the population and infrastructure.

Successful implementation of projects for backfilling technogenic cavities with a paste mixture requires an integrated approach that takes into account various factors. Careful analysis and consideration of technological, natural, ecological, social-economic aspects make it possible to optimize the process of backfilling, reduce risks and ensure sustainable development of territories.

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