Development and implementation of resource-saving technologies of artificial array formation in conditions of Safyanovskoe copper-sulphide deposit

A M Mazhitov¹, A A Vugov², P V Volkov¹, A P Gnedih¹

¹UMMC Technical University, Uspenskiy Av., 3, Verhnyaya Pyshma, 624091, Russia
²Nosov Magnitogorsk State Technical University, Lenina Av., 38, Magnitogorsk, 455000, Russia

E-mail: a.mazhitov@magtu.ru

Annotation. The analysis of the experience of underground mining systems and technology of backfilling operations showed a wide spread of chamber systems of development with different ways of laying-out space, as hardening mixtures and waste production. One of the important directions of improvement of chamber system development is to find new technologies for the formation of stowing massifs on the basis of the waste rock dumps and penetrations that reduce the cost of backfilling operations. The authors consider solution of an urgent scientific and practical task, consisting in the development and scientific substantiation of parameters of technology of formation of the backfill array by hardening injection, that is important for the science and practice of mining.

1. Introduction
Processing of Safyanovskoe copper-sulphide deposit is carried out by the chamber development system with downward extraction and backfilling the worked-out space hardening mixture. The undoubted advantage is the completeness of ore extraction in the preservation of the earth's surface. However, a significant disadvantage of the above-mentioned system development is the high level of resource intensity of production, so the use of it, especially in areas with low mineral content, leads to a decrease in economic efficiency development of mineral resources. In this regard, the question arises of a possible reduction of the cost of backfilling operations without impairing the efficiency development of mineral resources.

The economic efficiency of cleaning operations is possible due to the reduction or complete elimination of high-cost production of solid mixtures during the development of Safyanovskoe chalcopirite deposits through injection of the hardening backfill array.

2. Methods of research
In the work, the authors use a complex research method, which includes: analysis and generalization of the practice of filling operations during the mining of ore deposits by chamber development systems with a bookmark; mathematical modeling of the stress-strain state of the elements of the construction of the packing array by the finite element method; physical modeling of the laying process; analytical and statistical calculations; technical and economic analysis of the results.
3. The main part

Analysis and generalization of experience of application of the chamber systems of development and backfilling operations at domestic and foreign mines showed the possibility of using crushed rock as a backfill material [1-7], which is applied in practice of Ural mining, thereby reducing the cost of backfilling operations and the negative impact of mining wastes on the environment. In particular, the economic efficiency of cleaning operations is possible due to the reduction or complete elimination of high-cost production of solid mixtures by injection of hardening backfill array of bulk species [8, 9]. Implemented technology involves performing delivery and ventilation drifts of ventilation-way raise, which connects delivery and ventilation levels as well as a brown-carrier-vectors separating the ore body from the camera. Treatment cameras are shaped as a parallelepiped with the contact angle with the ore array of adjacent camera of 75-85 degrees and a stretch across the strike of the ore body. Cameras are processed in a continuous manner without leaving a mined-out space of the load-bearing pillars. The development of the front of mining operations within the floor from the center to the flanks, or one flank to another in an ascending order of development of deposits. Testing of the first camera starts with the rising penetration of the cutting and forming cutting slits. The breaking of the main stocks of the camera are provided on a reimbursable space of the cutting gap. The hanging side of the camera is formed at an angle of 75-85 degrees, and if working out from the center to the flanks, the central chamber has the shape of a trapezoid and, accordingly, the two-hanging side. The angle of the walls of the chambers in the direction of the goaf increases the stability of the backfill array. After stoping, the chamber is filled with waste rock. The next step is the hardening of the layer of rocks laying on the boundary of the ore array, by injection. Flow of cement mortar is produced by wells drilled from the workings of the vent floor. The number of wells is calculated from the radius of penetration of the solution into the breed, height and length of the chamber. Breaking stocks subsequent chambers are in compression environment, thereby ensuring that the seal is not lost mobility stowing the mating array camera. Assessment of the practical applicability and justification of technology for backfilling operations using injection of hardening backfill array was based on analytical calculations, physical and mathematical modeling, and pilot testing of the technology.

There are studies of the influences of the camera angle on the magnitude of lateral pressure, the chamber height and depth of mining, the width of the hardened layer of the backfill array.

The lateral pressure, created by the spoil tab, depends on the prism slippage, which in turn depends on the height, width and angle of the camera [10]:

$$G_{b_{\text{max}}} = \gamma S \cdot \sin \alpha / P \cdot f_1, \text{t/m}^2$$

where $\gamma$ – specific weight bookmark in cranky condition; $S$ – area of the cross section of the camera, m²; $P$ – perimeter of the cross section, m; $f_1$ – the coefficient of friction of the loose tabs on the chamber wall.

An epure of the distribution of lateral pressure is presented in figure 1.

![Epure pressure loose tabs on the hardened layer](image)

**Figure 1.** Epure pressure loose tabs on the hardened layer (1 – rock bookmark, 2 – the hardened layer)

The calculations showed (fig. 2) that the decrease in the angle of the camera leads to a decrease in
lateral pressure exerted by the pedigree tab. This is because reducing the slope angle, at constant other parameters of the camera leads to a change of the geometric dimensions of the prism sliding, by displacement of the weight of the rock laying on the enclosing rocks. Lateral pressure is taken at the optimal angle of 80° (the limit of the span of the outcrop ore of the array) and does not exceed 1.5 MPa. Thus, the strength injectisome layer (the hardened layer) is necessary and sufficient to create 1.5 MPa.

![Graph](image1.png)

**Figure 2.** The dependence of the lateral pressure of the granular backfill on the camera angle

Analytical calculations, on the basis of the dependence given in [11], obtained the necessary width of the hardened layer (for a given strength of 1.5 MPa) at different depths (Fig. 3b) and the width of the camera (Fig. 3b). The average width of the layer for conditions of Safyanovsky mine was 3-5 m. Physical modeling, performed using species of Safyanovsky mine makes up the possibility of creating a hardened layer with specified parameters.

![Graph](image2.png)

**Figure 3.** Dependences on thickness of the hardened layer depth of development (a) and the height of the camera (b)

With the purpose of the validation of analytical and laboratory studies, the mathematical modeling of the finite element three-dimensional formulation of the problem is given. The simulation results showed that the stresses are concentrated in the base of the artificial hardening of arrays, that is, in the place of fixing it. The values of the voltages do not exceed the strength characteristics of the hardened layer, which suggests that the calculated width provides a steady state. The results of the assessment of VAT are shown in a graph (Fig. 4).
Figure 4. The dependence of the maximum compressive stress for different values of the width of the camera

The estimation of the displacements relative to the vertical plane showed that a slight shift occurs in the upper part of the array, the base of the hardened array is not subject to offsets. This is because the basis of hardening of the array is clamped under the action of its own gravity, while the upper part is not jammed neither array containing rocks nor overlying the ore array. The nature of the change values of the maximum displacement of the artificial array, depending on its width, are shown in the graph (Fig. 5).

Figure 5. Dependence of the maximum displacement of the hardened layer with different values of the camera width

The decline of displacement indicators because of the increase in widths due to increased stability of artificial hardening of the array occurs by increasing its horizontal area. In general, the offset values are not significant and not enough to shift or overturn. The most dangerous stresses arising in artificial hardening the array are tensile due to the weak resistance of concrete to tension.

The analysis of the geomechanical model for this type of stresses in a hardened layer of rock under the action of bookmarks identified concentration areas, which are located in the base of hardening of the array. However, the limit value does not exceed the limit tensile strength of the hardened layer. The obtained values of maximum tensile stress for different values of the width of the cameras are combined in the chart (Fig. 6).
To clarify technology solutions for the formation of an artificial array by injection of hardening dry granular rocks was possible by industrial trials testing experimental plot of Safyanovskiy mine. Injection technology includes preparation of solutions, installation of injectors, transport and injection of the solution. For cooking, transportation, and injection of hardening solution, the authors use the existing surface backfilling complex.

Injectors are metal tubes with a diameter of 100 mm, perforated outlets for the passage of injection solution every 3÷5 m along the length of the injector. As a binder, the authors used cement milk when the ratio is C/A=1/3. The consumption of the components per 1 m$^3$ of the solution was planned as follows: cement – 300 kg, water – 900 L. The volume of the mixture required for testing – 110 m$^3$. As the filler, the authors used a dry tab in the form of waste rock from tunnelling works.

In the manufacture of the injection process 63 m$^3$ of cement grout was spent, including 18850 kg of cement, 56770 l of water. 54 m$^3$ of cement milk went to dry impregnation strata bookmarks; 9 m$^3$ emerged on the soil excavation in the process of pressure relief and flushing backfilling of the pipeline.

Subsequent testing of the adjoint camera K22-3-80 shows the stability of the strengthened layer of the backfill array. Significant dumped rocks’ influence on the coefficient of dilution was observed. Also the stability of a vertical wall has affected the ore crust with a capacity of up to 0.5-1 m formed by drilling and blasting operations. In the production of cleaning work and release of the ore mass from the chamber, the ore, the crust collapsed as a result of detachment from the backfill array, and did not affect the loss factor of the camera.

Thus, the proposed technology with the injection of the dry hardening backfill array is technically feasible and there is no doubt in its effectiveness. In addition, as an inert filler backfill mixture for filling of mined-out space, the authors recommend using the rock from dumps and mining operations. This allows you to utilize up to 500 thousand tons/year of rock dump and up to 100 thousand tons/year of rock with mining operations. Thus the enterprise has an opportunity to begin work on reclamation of waste dumps that contributes to the improvement of the environmental situation related to waste disposal, emissions of polluting substances in atmospheric air and discharge of surface waste water.

4. Conclusion
In the work, the authors gave the solution of an urgent scientific and practical task consisting in the development and scientific substantiation of technology parameters of backfill array formation by hardening injection, important for the science and practice of mining. There were studies of the influences of a camera angle on the magnitude of lateral pressure and the chamber height and depth of mining the width of the hardened layer backfill array. The calculations showed that the decrease in the angle of the camera leads to a decrease in lateral pressure exerted by the pedigree tab. Lateral pressure is taken at an optimal angle of 80° (the span limit of the outer ore of the array does not exceed 1.5 MPa). Thus, the strength of the injected layer (the hardened layer) must be 1.5 MPa. Analytical calculations obtained the necessary width of the hardened layer (for a given strength of 1.5 MPa) at
different depth and width of the camera. The average width of the layer in terms of Safyanovsky mine made up 3-5 m. Physical modeling, performed using species of Safyanovsky mine, creates the possibility of making a hardened layer with specified parameters.

The results of geomechanical studies indicate that compressive, tensile and shear stresses in the hardened layer generated under the action of rock, the tabs that do not exceed the specified limits of strength. This fact means that the hardened layer will be in equilibrium, will not collapse, and ensure the safety of mining operations when retrieving an inventory related camera.

Thus, the proposed technology with the injection of the dry hardening backfill array is technically feasible and there is no doubt in its effectiveness.

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