Increasing the stability of mine stopes by injection hardening of the near-contour mass

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Abstract. The possibility of improving the mechanization of strengthening the near-contour mass of stope is considered. Variants of improving the supply of injection solution into the mass are proposed, various technological schemes for supplying the injection solution into the near-contour mass are considered, and an optimal injection scheme is proposed. A classification of injection solutions is made in terms of the possibility of their use in rocks of different stability and injection technology.

1. Introduction
Modern trends in geotechnology are aimed at increasing the intensity of extraction of minerals [1]. With increasing loads on stopes and an increase in the speed of their penetration, the task of ensuring high reliability and safety during mining operation is quite acute [2]. The frequency of geotechnogenic disasters during the extraction of minerals is increasing [3]. Collapse of stope roof at the «Korbalikhinsky» mines in Altai Territory, «Sarylakh» in Yakutia, «Novo-Kalinskaya» in the Sverdlovsk Region, etc. occurred in two months of 2019. These are the largest disasters that have led to the shutdown of the mine. These destruction cause vibrations in the earth's crust, the influence of which was studied in [4]. Vibrations spread over long distances [4] and affect underground stopes, as well as buildings and structures located on the surface [5]. The possibility of reducing the economic and environmental consequences of man-made disasters by creating a compulsory insurance mechanism is considered in [6]. Some disasters led to the formation of sinkholes on the earth's surface, the destruction of the mine and the loss of mineral resources [7-9]. In addition, geotechnogenic disasters have a negative impact on the environment and pose a threat to environmental safety [10-14]. The issues of preserving the primordial and mineral diversity of the Earth and the possibility of transferring mining to space bodies [1] and the legal framework are considered in works [15, 16].

2. Consolidated hardening
Consequently, the main direction in preparatory and mining works is the creation and implementation of machines [17], mechanisms and equipment that allow the application of the current technology of
fastening of stopes [18], ensuring reliability, safety and efficiency [19]. It is necessary to create equipment for injection hardening and develop technologies that allow in difficult mining and geological conditions to change the physical and mechanical characteristics of disturbed rocks in the near-contour zone of stopes. This will provide an opportunity to effectively manage the state of the mass [20-22].

The most effective direction is the simultaneous use of a rod attachment with subsequent injection of solutions. In this case, we get a consolidating support, which is characterized by a combination of various interconnected elements: support - reinforced near-contour zone - mass. In this case, there is a high probability to ensure the necessary safety, reliability and stability of the mine. Such consolidation eliminates the displacement and rotation of individual sections of the near-contact zone of the stopes and increases the strength of disturbed rocks.

To implement this technology of consolidated rock hardening of the near-contour zone, the following scheme must be adopted: drilling holes in the roof immediately after its exposure; installation of injection rods in the borehole and their tension; preliminary hardening of the bar; injection of a hardening composition into the mass. The adopted hardening scheme excludes the separation of rocks in the injection zone, ensures the restoration of the natural strength of rocks and prevents their subsequent spalling. In this scheme, the boreholes perform a double function: they serve to install and secure the rods; are used to supply injection solution to the mass. With this scheme, it is possible to use different rods with different types of attachment.

3. Choice of material for injection
When choosing a material for injection, it is necessary to take into account the technical and economic indicators. On the one hand, from the point of view of efficiency and minimization of fastening costs, it is necessary to use cement-based materials. But these solutions have a number of disadvantages: unstable quality of cementation of the near-contour zone of stope; stratification of the solution at the time of injection; an increase in the total resistance to injection occurs with an increase in the injection depth; the presence of water contributes to the soaking of the rocks of the near-contour zone, which temporarily reduces their strength. The use of mechanical activation of components makes it possible to increase the stability of cement slurries, while increasing the strength properties [23]. The properties of such solutions were analyzed in [24]. It is possible to reduce the cost of injection solutions by using technogenic waste [25], which reduces the impact of mining on the environment [26].

Taking into account the technical indicators, the most worthy of attention from a scientific and industrial point of view are solutions based on polymer materials: urea; phenol formaldehyde; polyurethane; polyester; epoxy; chloromagnesium; organo-mineral, etc. The main factors for the possibility of using polymeric materials for fastening the near-contour zones of stopes are: high penetrating ability; high plasticity; stable quality of strength throughout the entire depth of penetration; the ability to adjust properties immediately before feeding into the well; short setting times. However, these solutions have a number of disadvantages: high cost; some solutions are toxic; fast setting of some solutions; some solutions become brittle after setting.

The rocks and ores of the mines, which are prone to cracking and collapse, are very diverse. According to the degree of moisture, the near-contour mass can be in any state: from dry to wet. Studies of different penetrating ability in watered and dry soils were carried out in [27]. The temperature of the hardened rocks at the mines is in the range of 5-30 °C, and in the regions of the north in minus intervals up to -10 °C. In addition to the natural state of the near-contour mass of stopes, the degree of crack opening is of great importance when choosing an injection solution for strengthening it. If the crack opening width is small (up to 1 mm), then the bond strength of the blocks is determined by their functional bond and is characterized by the adhesion of the composition in nature. If the crack opening width is significant (2-5 mm), then it is necessary to take into account the cohesive strength of the composition itself, since the system "rock - strengthening composition" works like a composite of two materials. In this case, the strength indicators of the hardened injection material should approach the corresponding indicators of the rocks of the near-contour zone.
Polymeric materials used to strengthen the near-contour mass must have a significant viability after mixing the feedstock, intensively penetrate into cracks and harden in specified time intervals. The absence of fragility and shrinkage is one of the main properties of strengthening solutions. Fragility with an insignificant manifestation of rock pressure or any influence of mining operations on the mass leads to disruption of the “rock - strengthening composition” connection.

The shrinkage of the binder composition in cracks of large volume leads to the formation of new microcracks and a decrease in the strength and stability of the fixed mass. The opposite of shrinkage is the property of increasing the volume of the solution after hardening. This property is positive for injection solutions, since in the process of increasing the volume at the moment of solidification, additional bonds and expansion forces arise. This contributes to the maintenance of a state of equilibrium. The hardened mass, both during the solidification of the solutions and after their solidification, can undergo shearing deformations as a result of the action of rock pressure or drilling and blasting operations. Consequently, the injection solutions should be flexible during hardening and elastic after final hardening.

Both of these requirements contribute to maintaining the equilibrium state of the fortified blocks of the near-contour mass with small mutual displacements. When the mass is hardened in contact with the ore body, part of it may undergo the penetration of the injection solution, which may adversely affect later in the enrichment process. Consequently, the composition of the injection solution must completely exclude a negative effect on the ore preparability. These requirements are quite stringent when choosing an injection composition. However, the properties of injection solutions are not permanent.

As a result of activation of various components of the solution and the solution as a whole, it is possible to change both the properties of the solution and the properties of the final homogeneous mass [11-13, 21, 23, 24]. Waste from concentrating factories can be used as activators [11]. The analysis of a large number of injection solutions made it possible to classify them from the point of view of the possibility of their application in rocks of different stability and injection technology (figure 1).

Materials outside zone C are unacceptable for use as injection solutions when strengthening the near-contour zone of stopes.

4. Equipment for mechanization of injection works
To perform work on injection rock hardening a certain combination of several groups of equipment is required:
- equipment for well drilling;
- control and measuring equipment;
• equipment for injection of strengthening chemical compounds.

For drilling injection wells and boreholes, standard serial equipment is used, similar to that used in mining works. Manometers, thermometers and flow meters are used as control and measuring equipment for the injection of injectable fixing composition. Devices for monitoring the flow rate of the injected composition make it possible to determine the degree of saturation of the mass during the injection process. Such devices include turbine, mass, ultrasonic and induction meters.

The use of the flow meter is due to the physical and chemical properties of the injected composition. However, it should be noted that ultrasonic flow meters are most versatile, while induction ones are highly reliable. The quality of work with the injection method of strengthening depends on the control and determination of the physical and mechanical properties of the rocks, the zone of distribution of the solution, the direction of the injectors and compliance with the specified injection parameters. The study of the characteristics of the rocks of the strengthened and injected mass can be carried out using geophysical methods, such as electrical, radioactive and acoustic logging. The main task of this study is: mechanization of work on strengthening the contour mass of stopes and the choice of a technological scheme for injection.

When carrying out work, it is possible to use various technological hardening schemes, which are subdivided according to the following features:
1. the time of the work on strengthening in relation to mining operations;
2. a method of forming a hardening composition from components;
3. test mode.

According to the first feature, the hardening schemes can be divided into:
• advanced hardening (preliminary hardening of the rock mass);
• subsequent hardening;
• simultaneous hardening (hardening from the mine face simultaneously with the production of mining operations).

According to the second feature, injection schemes can be divided into:
• single-solution scheme, which consists in preliminary preparation of the solution and its injection into the mass (Figure 2 a);
• mixed scheme, which consists in separate supply of components under high pressure and mixing them immediately before injection (Figure 2 b);
• double-solution scheme, which consists in separate injection of components (Figure 2 c).
Figure 2a. Single-solution scheme
1-mixer; 2-pump; 3-container for resin; 4-container for hardener; 5-hose; 6-high-pressure hose; 7-injector.

Figure 2b. Mixed scheme
1 mixer; 2-pump; 3-container for resin; 4-container for hardener; 5-hose; 6-high-pressure hose; 7-injector; 8-hose recirculation.

Figure 2c. Double-solution scheme
1-mixer; 2-pump; 3-container for resin; 4-container for hardener; 5-hose; 6-high-pressure hose; 7-injector; 8-hose recirculation.
According to the third feature:

• clamping mode;
• circulation mode.

The injection technology with advanced, subsequent and simultaneous hardening practically does not differ. The single-solution injection scheme makes it possible to most strictly maintain the ratio of the components, since the composition is prepared in advance. Disadvantages of the scheme:

• the need to take such a ratio of components in which the gelation time would be at least 40 minutes;
• impossibility of technological breaks until the complete consumption of the prepared composition, because this causes the composition to harden in the equipment;
• high labor intensity of maintenance associated with the need to clean and flush equipment after each injection cycle.

The mixed injection scheme is the most versatile. It allows to create a wide range of changes in the gelation time, the ratio of the components can be taken so that the gelation time is reduced to 3-5 minutes. The hardening composition is formed immediately before it is fed into the hole, the danger of the composition hardening in the equipment is eliminated, and the time for servicing the injection equipment is reduced.

The double-solution injection scheme is unacceptable for injection hardening with polymeric materials. It is used when using compositions based on silicate binders or silicate-polymer binders. In case of injection hardening of rocks in underground conditions, the supply of the hardening composition is carried out only in the clamping injection mode.

5. Conclusion

Summing up the analysis carried out, it should be concluded that in the developed equipment it is necessary to adopt a mixed injection scheme, which, if necessary, can be easily transformed into a single or double-solution scheme. It is necessary to conduct research to study the radii of propagation of various injection solutions in the near-contour zone, depending on the fracture and the size of the crack opening when using this equipment and the selected injection scheme.

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