Experience of application of polyurethane and phenolic resins in roadheading in fractured and heavily disintegrated rock mass

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Abstract. The problem of mining and ground support in an unstable rock mass under stoping is discussed. The analysis of the experience gained in application of phenolic and polyurethane resins to fill domes-like voids and for preventive consolidation and roadheading in disintegrated rock mass is presented. The feasibility to fill domes formed under roof caving with Blockfil phenolic resin in combination with grouted bolting and the use of Blockpur polyurethane resin for consolidation of disintegrated rocks is investigated. The laboratory test results on strength properties and time of polyurethane resin flowability loss are presented. The procedures are developed for eliminating accidents due to dome formation under roof and sidewalls collapse, as well as for the support of weakened roadways by yielding steel arcs. It is emphasized that geotechnical conditions worsen due to dome formations during recovery works in mines.

1. Introduction
The Orlov deposit of polymetallic sulphide ore features difficult geological and geotechnical conditions. Massive barite–polymetallic and copper–zinc ore as well as massive and disseminated sulphuric copper ore and varieties possess high strength and elasticity. Therefore, mining operations in such conditions should account for risk of dynamic phenomena of rock pressure.

The strength of rocks drops in the zones of weathering, dislocation and hydrothermal alteration from a few meters to 100–150 m thick [1]. Adjacent rocks are very unstable, with numerous differently oriented micro-joints with calcite and pyrite fill, and many slickensides. Under exposure, relaxation of high stress and wetting, such rocks become soft and fall in mine roadways.

Ground support in roadways in unstable rocks (stability category IV) in Orlov Mine includes SVP-22 steel frames and with timber cushioning of voids in back of the support. In difficult ground conditions (in unstable rocks) under higher stress state, steel frames are greatly deformed and roof rock fall in large volumes. As a result big “domes” form in the roofs, which makes roadways prone to accidents and dictates by-pass road heading [2].

For example, in January 2018, loosening of damaged rocks occurred in the roof and sidewalls in haulage no. 1 of level 15 under construction by Vostokshakhtstroy. As a result of collapse of the roof and sidewalls in the roadway, the estimated volume of voids was 140 m³, including dome volume of 90 m³, volume in cross section of 15 m³, volume of voids in back of the metal frame support of 35 m³.
The experience of mining knows different resins used for filling “domes” or for advanced reinforcement of damaged rock mass, for instance, in mines of the Polar Division of NorNickel, Kaz Minerals and Kuznetsk Coal Basin [3–6]. Injection reinforcement of rocks enjoys wide application in coal mines in Kuzbass [7–11], in shafts of Udachny Mine of ALROSA [12] and at Don Mining and Processing Plant [13, 14]. Technologies of preliminary cementation of heavily jointed rocks are known as well [15–17]; for instance, in Orlov Mine, heavily damaged and jointed rock mass was reinforced by injection with micro-cement [18].

2. The technology of voids healing by phenol resin: practical results

Aimed to heal voids after rock falls in roof and sidewalls, as well as in order to support the accident span with SVP-22 steel yielding arch support, jointly with DSI Tekhno, the following technology was proposed. It was planned to fill of voids in the rock fall section, over the entire cross-section of the roadway, with BlokFil foaming phenol resin and, then, to undertake the advanced injection of roof rocks with Blokpur polyurethane resin. The characteristics of Blokpur resin are compiled in Table 1.

| Description                        | Component A       | Component B       |
|------------------------------------|-------------------|-------------------|
| Density at 25°C, g/cm³             | 1.12 ±0.1         | 1.22 ±0.02        |
| Color                              | Transparent to light-yellow | Dark-brown       |
| Flash point, °C                    | > 200             | > 200             |
| Viscosity at 25°C, MPa·s           | 300 ±100          | 200 ±100          |

The polyurethane resin had compressive strength of 24.61 MPa by the data of lab-scale experiments at the certification experimentation center of the East-Kazakhstan State Technical University, or 64.51 MPa at 10 % deformation in the age of 2 h by the DSI Tekhno testing results. The flowability loss time at +25°C was 44 s.

Figure 1 depicts the sequence of heading and re-support in haulage roadway no. 1 (Figure 1). First, voids in the back of 8 frames in the roof and sidewalls are filled with BlokFil foaming resin. Then, in the dome, along the sidewall and roof, two steel feed types with a diameter of 50 mm are laid to guide plastic injection pipes (3 pipes, 2 m long each) to feed the resin. Injection is started in tube 1 installed in the sidewall. After its filling (approximate volume of 20 m³ ~ 90–1000 kg of BlokFil resin), injection is initiated in tube 2 (approximate volume of 30 m³ ~ 1400–1500 kg of resin). After that, a light timber apron walls is installed, and filling of residual voids is completed.

When the voids are filled and the phenol resin is cured, the hardened resin is removed within the project cross-section of roadway, by small batches, for the installation of one steel frame. The spacing of the frames in the rock fall section is recommended to be not wider than 0.5 m. After installing and straining of the first frame, the second frame is mounted, etc. In this manner, the whole accident section to a pillar (face) is covered. Before face drilling, in the roof of the roadway, advanced injection bolts DIVI Drill are installed using a self-propelling drill rig or hammer hand drills.

After rock bolting to a depth of 4 m (two 2 m long coupled rock bolts), in the internal hole of each bolt, the reinforcement mixture is injected—two-component polyurethane resin Blokpur. Rockbolting is made in the roof, at an angle of 20–25° to the longitudinal axis of the roadway to a depth of 3.8 m (bolt end of 200 m is left outside to be connected with the injection equipment). The spacing of the rock bolts is 0.5–0.7 m, and there are 6 rock bolts installed in the roof of the roadway 4 m wide.
The approximate consumption of Blokpur per one injection DIVI Drll bolt is 30 kg. After completing the rock bolting, drilling is started in the roof for the advanced injection reinforcement. Between the DIVI Drill bolts, three holes with a diameter of 43 mm are drilled to a depth of 3 m in the roof at an angle of 40–45° to the longitudinal axis of the roadway. In the holes, in turn, a sealer with the injection pipes is installed, the injection equipment is connected and Blokpur resin is injected under pressure of 80–100 bar at the rate of 144 kg per injection hole. Then, heading is carried out to a length of 2.5 m, by cuts of 0.5 m and with spacing of the installed steel frames of 0.5 m. After that, the advanced reinforcement and injection cycle is repeated. In case that the cross-section of the roadway enlarges during the heading, the new voids are filled with BlokFil resin. Finally, the actual condition of the roof and sidewalls in the roadway is evaluated with a view to assessing potentiality of the further heading without advanced reinforcement.

In order to heal voids after rock falls in the roof and sidewalls, as well as to reinforce the accident span of the roadway with steel yielding arched support, in haulage roadway no. 1 on level 15 in Orlov Mine, 120 m³ of BlokFil phenol resin was injected in the gap between between the support and rocks inside the interval of 6 installed frames. Then, the pre-installed apron wall was removed. Prior to continue heading, in the face roof of the roadway, advanced injection DIVI Drill bolts 4 m long were set in two stages at an angle of 20–25°. In the first stage, 0.5 away from the last frame, five bolts were installed to be injected with two-component mix Blokpur, as well as three holes with a diameter of 51 mm were drilled to a depth of 3 m for the injection of Blokpur resin by a sealer with the injection pipes at a pressure of 80–100 bar. In the second stage, 2.6 m away from the first frame, five DIVI Drill bolts...
bolts were installed and filled with Blokpur, as well as one injection hole was drilled and filled with the resin. Furthermore, other three holes were drilled for the injection of Blokpur to reinforce rocks.

The total volume of injected polyurethane resin Blokpur was 1056 kg. All in all, 15 SVP-22 steel frames were installed with spacing of 0.6 m, which makes a span of 7.2 m in the damaged roof from the entrance of haulage roadway no. 1. In this fashion, the section of doming filled with foaming BlokFil resin was passed. It should be mentioned that at frame 12, geotechnical conditions worsened with rock falls from the roof, left sidewall and face. The looseness parameters were: doming 3. M high above the SVP-22 steel frames and to 1 m in the left sidewall; no loosening of rocks were observed in the right sidewall. The total rock fall volume was 25.7 m³. It was recommended to fill the voids with BlokFil to avoid further doming. Heading was advised to continue suing jackhammers. Drilling and blasting was only permitted at the bottom of the right sidewall by 2–3 holes 0.5 m long and small explosive charges.

In ventilation cross heading 9 on level 13 in Orlov Mine, loosening of damaged rock mass took place in the roof and sidewalls with the prediction volume of voids of 140 m³. Aiming to heal domes and recover the mine support in that section, a new approach was proposed. First, it was required to fell gaps in back of the support in the roof and sidewalls within the 40 m-long interval of 8 pre-installed frames with foamed phenol resin BlokFil (Figure 2). The estimated consumption of BlokFil was 1350 kg. Then, strapping made of round wood was made on four frames nearby the rock fall; at the same time, into the dome, along the roof of the heading, two steel feed tubes with a diameter of 50 mm were laid. Using plastic pipes 2 m long, filling of gaps between the support and rocks with BlokFil was completed. Through the steel tubes, plastic injection pipes (6 pipes, 2 m long each) were driven in the dome for the complete filling of the void with phenol resin (approximate consumption of BlokFil was 4950 kg). From the reinforced boundary toward the fallen-in rock mass, DIVI Drill R32-360 injection bolts 3 m long were drilled at an angle of 30–35° to the longitudinal axis of the heading to a depth 2.8 m (the bolt end 200 m long was left outside for the connection of the injection equipment). The spacing of the bolts was 0.5–0.6 m, 18 bolts were installed. After that, the bolts were in turn connected with the injection equipment, and Blokpur resin was fed in the fallen-in rocks under pressure. It was advised to inject resin starting from the lower bolts.

![Figure 2](image.png)

**Figure 2.** Schematic of healing the dome and re-support in the damaged area of ventilation crossheading no. 10 in layer 9 on level 13.
The expected consumption of Blokpur resin per one DIVI Drill injection bolt in the conditions of fallen-in rocks is 96 kg. The fallen-in rocks are carefully removed using LHD in such amount that one steel frame can be installed. The frames are set and strapped with wood at spacing of 0.5 m. The gaps in back of the support are filled with phenol resin BlokFil. These operations in the indicated sequence are fulfilled in the span of 2 m of the crossheading, and the cycle is repeated.

Consumption of materials for the void volume of 140 m³ in haulage roadway no. 1 was:
— phenol resin BlokFil—6300 kg (voids) and 900 kg (in back of the support);
— DIVI Drill—24 bolts (2 m long);
— polyurethane resin Blokpur—1224 kg.

The cost of materials and ancillaries for the breakdown elimination in haulage roadway no. 1 on level 15 made 1917 Rub, including 1375 Rub for phenol resin and 301 thou Rub for polyurethane resin. Furthermore, the rent cost of the two-componet pneumatic pump was 22 thou Rub per moth. Thus, the cost of materials and ancillaries at the void volume of 140 m³ was 13.6 thou Rub/m³ or 1917 thou Rub in the accident span 7 m long. Given the cost of development heading of 5 thou Rub/m³ in Orlov Mine, the cost of driving a by-pass roadway 7 m long makes 490.3 thou Rub, which is much less than the cost of recovery of the heading using phenol and polyurethane resins.

The estimated consumption of materials at the void volume of 140 m³ in ventilation crossheading no. 10 with drilling and advanced reinforcement of the roof span 8 m long using DIVI Drill bolts is:
— phenol resin BlokFil—4950 kg (voids) and 1350 kg (in back of the support);
— DIVI Drill—72 bolts (3 m long);
— polyurethane resin Blokpur—6912 kg.

3. Conclusions
1. The technology developed and trialed in Orlov Mine in healing of voids by foaming phenol resin with advanced injection of rocks with polyurethane resin and with re-support of roadways by steel frames made it possible to eliminate accident in the conditions of roof rock fall, and to recover safety of mining.
2. The commercial trial of the technology showed that the cost of materials for the recovery of underground excavations using phenol and polyurethane resins is currently essentially higher than the cost of by-pass heading: 13.6 and 5.0 thou Rub/m³, respectively.

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