Reducing the cost of backfill in the Kauldi gold mine

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Abstract: The Kauldi gold mine uses the backfill to control the mining pressure. Backfill should be able to effectively manage the pressure of the deposit, ensuring safe working conditions, easier preparation process as well as little funds. The cost of backfill directly affects the cost of ore and is important for the indicators of economic development of the mining enterprise. In this article, the method of reducing the costs spared by making changes to the composition of the backfill used in the Kauldi gold mine has been studied. Ore extraction is carried out in the stopes. After the primary stope is extracted and filled with backfill, the secondary backfill is extracted and filled. In the proposed method, 1/3 of the primary stope and 2/3 of the secondary stope are filled with burden. The remaining parts are left unchanged. The reason for such a distribution of the burden in the stopes is that if the backfill in the primary stope is not sufficiently solid, the ore can also be diluted and the backfill is broke-down when extracting the secondary stope. If this happens, the ore will degrade and cause excessive backfill costs for the secondary stope. Filling the stopes with burden is considered cost-effective, and in general, the amount of cement, sand, as well as marble waste purchased for the mining enterprise is reduced twice. As a result, the costs spent on them will also be reduced twice.

1. Introduction

The extraction cost of ore deposits by underground mining method is considered high. As the depth of mining increases, various problems begin to arise. Kauldi gold mine is no exception. The process of backfill preparation, to control the rock pressure, is somewhat complicated, as well as time and energy costs. This is due to the fact that the burden, which was extracted during the tunneling, is removed to the surface with the help of load-haul-dump machines and crushed to a certain size in the crusher, and then transported to the backfill preparation area [1]. Once prepared, paste backfill is transported (or pumped) and placed underground by pipeline reticulation. The governing elements of paste backfill transport are rheological factors such as shear yield stress, viscosity, and slump height (consistency) [2].

During the last few decades, cemented paste backfill (CPB) has become increasingly popular in underground mining operations worldwide [3]. In addition to the efficient disposal of mine or processing waste, other benefits of the CPB technology include improved working environment, increased resource recovery and improved ground controls. Furthermore, this technology is also
considered superior to conventional slurry backfill methods in terms of both the economic and environmental benefits. All of these technical, economic and environmental advantages associated with the use of CPB have resulted in wider acceptance of its application [4]. In a cut-and-fill mine, mining is conducted in horizontal slices by drilling and blasting, starting from the bottom of the stope. As the stope reaches a particular height, the mined stope is filled with economical backfilling material, which basically serves as the working floor for mining the next slice in addition to providing some degree of confinement to the stope walls. Therefore, the height of the gap between backfilling surface and stope back is controlled such that the drilling and blasting of the next slice can be done without difficulty [5]. Currently, inert materials such as cement, sand, as well as marble mine waste are used for the cemented paste backfill in the mine [6]. A significant part of the cost of ore extraction in the cut and fill mining (up to 15-25%) is due to the filling [7]. The purpose of the research work is to reduce the cost and time spent on preparation of backfill. In order to achieve the intended purpose, a certain part of the burden in the Kauldi gold mine is not removed to the surface and placed on the excavated stopes. Then the amount of filling prepared for the primary and secondary stopes is significantly reduced compared to the previous one. As a result, the consumption of cement and marble waste, which are part of the backfill, is reduced. At the same time, there is no cost for winding the part of the burden to the surface, for transportation to the site of crushing and backfill preparation.

2. Method
Underhand cut-and-fill stoping is an efficient, sustainable mining method that is particularly applicable to complicated mining conditions in which both the peripheral rocks and the orebody are extremely unstable [8]. However, extraction by cut and fill mining across the entire mine field causes an increase in the ore cost. The presence of the possibility of backfill preparation with the use of burden in the filling cavity itself, the maximum safe conduct of work, simplification of the process, reduction of the cost of mining and filling is the most promising construction of filling the stope [9]. The proposed method is carried out as follows. Filling the first stope: the stope varies in height and width from 3×3.5 to 5×4, one third of the volume of the stopes are filled with burden and evenly distributed over the entire length of the stope. The burden, which is used as a backfill in this method, should be located in the middle of the stope (Figure 1).

![Figure 1](image_url)  
**Figure 1.** The scheme of placement of the backfill made of burden in the primary stope: b and h respectively the height and the width of the stope.

The surface of the burden, used as a backfill in the stope, is as follows

\[
S_b = \frac{S_{ABCD}}{3}
\]

(1)

here \(S_b\) is the surface of the burden in the stope, \(S_{ABCD}\) - the surface of the stope. The remaining two-thirds of the primary stope, that is, the two walls and the ceiling are filled with a backfill. Because the backfill in it should be solid. If it is not strong enough, when the secondary stope
excavated through the right and left sides of the primary stope, part of the backfill along with the ore can collapse and mix. If such cases occur, the following negative consequences will occur:
- ore dilution will increase;
- the volume of the extraction stope exceeds the project volume, which leads to an increase in the cost of filling;
- has a negative impact on the intensity of mining;

All of the shortcomings listed above lead to an increase in the cost of ore.

The liquid contained in the backfill is absorbed into the burden, and the liquid solidifies to a certain extent. After the sufficient solidification of the backfill in the primary stope, the extraction of the secondary stope begins (Figure 2).

Secondary stope filling: two-thirds of the stope is filled with burden, while the remaining one is filled with a backfill. The reason why two-thirds of the secondary stope filled with burden was because ore mined by the primary stope on the sides. For this reason, only the upper part is filled with the backfill (Figure 3), so that its upper part can be excavated.

![Figure 2. General view of the backfill in the primary stope](image)

![Figure 3. Scheme of filling the secondary stope](image)

For artificial chain pillars the greatest load per unit length is determined by the formula [10].

\[ Q = n_1 \ast n_2 \left[ \gamma \ast H (a + b) + \gamma_0 \ast h \ast a \right] \]

(2)

here \( n_1 \) - reserve coefficient; \( n_2 \) - the coefficient, which affects the angle of inclination of the ore body; \( \gamma \) and \( \gamma_0 \) - specific weight of rock and backfill, t/m³; \( H \) - mining depth, m; \( h \) - pillar height (stope height), m; \( a \) - pillar width, m; \( b \) - stope width, m.

The holding capacity of a unit of length of the pillar is as follows.

\[ P = \sigma \ast a \sqrt{\frac{a}{h}} \]

(3)

here \( \sigma \) - uniaxial compressive strength of the pillar
The reliability of the pillars is determined by the equalization of the right sides of the equation (2) and (3).

\[ \sigma \cdot a \sqrt{\frac{a}{h}} = n_1 \cdot n_2 \left[ \gamma \cdot H(a + b) + \gamma_0 \cdot h \cdot a \right] \]  

(4)

The uniaxial compressive strength limit of the backfill for the pillar (4) is determined as follows, depending on the equation \( \sqrt{\frac{a}{h}} = 1.15 - 0.15 \frac{h}{a} \).

\[ \sigma = n_1 \cdot n_2 \cdot \frac{\gamma \cdot H(a + b) + \gamma_0 \cdot h \cdot a}{1.15a - 0.15h} \]  

(5)

The approximate value of the compressive strength of the pillar can be determined by the following formula.

\[ \sigma = n_1 \cdot \gamma \cdot H \cdot s \]  

(6)

here \( s \) - coefficient, which takes into account the ratio of the area of the ceiling, supported by the pillar to the square of the pillar. The volumetric weight of the filling material depends on the specific weight and quantity of the constituent part of it. The volumetric weights of most common additives that make up the composition of the filling materials are below (Table 1).

| Type of backfill          | Specific weight, t/m³ | In the solution state | In the massif |
|---------------------------|-----------------------|-----------------------|--------------|
| Fine-grained sand         | 2.0                   | 1.8                   |
| Crushed rocks             | 2.2                   | 2.0                   |
| Carbonated slag           | 1.9                   | 1.7                   |
| Boiler slag               | 1.8                   | 1.6                   |

The coefficient of influence of the dip angle of the ore body takes into account the reduction of the load on the pillar. As the dip angle of the ore body increases, the load decreases. If the pillar is oriented along the strike, then

\[ n_2 = \frac{m \cdot \sin \alpha}{\cos \beta \cdot \sin (\alpha - \beta)} \]  

(7)

here \( m \)-is the coefficient that evaluates the effect of external pressure compressing backfill mass on the side walls; \( \alpha \) - dip angle of the ore body, degree, \( \beta \)- the angle between the strata normale and the pillar axis.

For the pillar oriented along the dip angle of the ore body.

\[ n_2 = \cos^2 \alpha + m \cdot \sin^2 \alpha \]  

(8)

| \( \alpha \), degree | 0   | 10  | 20  | 30  | 40  |
|----------------------|-----|-----|-----|-----|-----|
| For square-shaped pillar (according to location) |
| According to the direction \( n_2 \) | 1   | 0.99| 0.97| 0.93| 0.87|
| Directed upwards \( n_2 \) | 1   | 0.99| 0.94| 0.88| 0.79|
When the pillars are oriented at an upper angle, it is possible to reduce the amount of shear reinforcement and the accumulation of reinforcement in the monolithic massif. The coefficient of impact of the dip angle of the ore body for the pillars is shown in Table 2. It is desirable to take a reserve coefficient of strength \( n_1 = 1.5 - 2 \), taking into account that the strength limit of the backfill increases for a long time.

The ratio of water mass to cement mass in a concrete mixture \( \frac{W}{C} \) is called the ratio of water to cement. For hard concrete \( \frac{W}{C} = 0.3 - 0.4 \); for soft concrete \( \frac{W}{C} = 0.7 - 1.4 \).

In the preparation of the backfill, we can use the cement marks shown in the table below (Table 3) [11].

**Table 3. Cement marks**

| Concrete brand (required uniaxial compressive strength, MPa) | \( 1 \text{ m}^3 \) cement consumption in dry mixture, kg | Relative composition of large additives in dry mixture |
|-------------------------------------------------------------|--------------------------------------------------------|-------------------------------------------------------|
| M300 (30)                                                   | 250                                                   | 0.2-0.3                                               |
| M400 (40)                                                   | 300                                                   | 0.3-0.4                                               |
| M500 (50)                                                   | 350                                                   | 0.4-0.5                                               |

For the preparation of backfill, we use cement of the brand M300. The consumption of materials used for the preparation of \( 1 \text{ m}^3 \) of backfill, which withstand the pressure of 22 MPa, is presented in the table below (Table 4).

**Table 4. The consumption of materials used for the preparation of \( 1 \text{ m}^3 \) of backfill**

| №  | Materials                        | For \( 1 \text{ m}^3 \) backfill, kg |
|----|----------------------------------|-------------------------------------|
| 1  | Cement, M300 brand               | 183.3                               |
| 2  | Sand (crushed burden)            | 1380                                |
| 3  | Marble processing waste          | 440                                 |
| 4  | Water                            | 220                                 |

3. Results and Discussion

The results of the calculation show that the total volume of the backfill and burden, which are placed in the primary and secondary stopes, is equal to each other and is presented in the table below (Table 5).

**Table 5. The total volume of the backfill and burden**

| Stopes          | Burden, \( \text{m}^3 \) | Backfill, \( \text{m}^3 \) |
|-----------------|--------------------------|-----------------------------|
| Primary stope   | 175                      | 350                         |
| Secondary stope | 350                      | 175                         |
| Total           | 525                      | 525                         |

The volume of the primary and secondary stopes together is equal to \( V = 1050 \text{ m}^3 \). For the preparation of \( 1 \text{ m}^3 \) cemented paste backfill, 183 kg (0.153 \( \text{ m}^3 \)) Cement and 1820 kg (0.847 \( \text{ m}^3 \)) inert materials are used. When both stopes are filled with the backfill, 160.65 \( \text{ m}^3 \) (192780 kg) cement and 889.35 \( \text{ m}^3 \) inert materials are spent on the entire space. In the preparation of the backfill for both stopes, cement (cement price of the brand M300 is 0.05 $/kg) costs 9639 $ and the inert material (1 \( \text{ m}^3 \) inert material price is 5 $) costs 4447 $. The price of \( V = 1050 \text{ m}^3 \) backfill is 14086 $.
The cemented backfill is considered one of the most expensive types of filling materials [12]. And in the applied method, the amount of use of the additive backfill in the filling of the stopes is reduced twice. As a result, the cost of the additive filling is reduced to $7043 per dual stope.

The annual work productivity of the Kauldi gold mine is 100000 tons (333333 m³). For a year 333333 m³ space is filled. The price of 1 m³ cemented paste backfill is 13.5 $. If the extracted cavity is filled with a backfill of the entire volume, it costs 444 995 $. When the proposed method is used, the costs are reduced twice. Then the enterprise will save 224 998 $ a year.

Alternatively, on account of the fact that half of the burden is placed in the stopes, twice as little material and energy is spent to remove it to the earth surface. That is, profitable mining trucks spend twice less fuel, its service life also increases. In one year, it will save a total of 28 000 $. On account of the decrease in the amount of cemented paste backfill and fuel consumption, the enterprise will save 252 998 $ sums in a year. As a result, the cost of ore, which is extracted, is reduced. This in turn has a significant impact on the enterprise’s position in the international market and the increase in profitability.

4. Conclusions
(1) according to the results of the calculation, it was determined that the use of burden in filling the stopes would reduce the consumption of cement and marble waste by 2 times, and as a result, the cost to them would also decrease by 2 times.
(2) it was calculated that the cost of winding the part of the burden into the surface of the surface, crushing and transporting to the backfill preparation area would be saved.

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