Arch. Min. Sci. **63** (2018), 1, 83-98

Electronic version (in color) of this paper is available: http://mining.archives.pl

DOI 10.24425/118887

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A NOVEL CLEAN MINING TECHNOLOGY INVOLVING THE UNDERGROUND DISPOSAL OF WASTE ROCK IN COAL MINES

NOWATORSKA CZYSTA METODA WYDOBYCIA OBEJMUJĄCA PODZIEMNĄ LIKWIDACJĘ SKAŁ ODPADOWYCH W KOPALNIACH WĘGLA

Coal enterprises are continually working to develop clean mining technology in order to maintain sustainable development, especially under the background of structural reform of China's coal industry supply side. Within this field, leaving waste rock underground in coal mines is a major area of interest for clean mining of coal resources. In order to address the root cause of problems with waste rock treatment and produce an environmentally friendly coal mining operation, this study begins from the mining technical conditions of Gaozhuang Coal Mine, analyzes the main source of underground waste rock, and puts forward the methods of "filling underground abandoned zone" and "acting as main aggregate of concrete" based on different output locations and subsequent functions of the waste rock. A centralized sorting system of waste rock has been established, which has effectively eased the mine hoisting capacity limitations. On this basis, through utilizing waste rock as the main aggregate of concrete, a novel technology of gob-side entry driving with preset packwall has been developed. This novel technology improves the recycling rate of coal resources, solves the problem of waste rock disposal, makes clean mining possible, and achieves great economic and social benefits. At the same time, these research results have provided theoretical guidance about clean mining technology for other coal mines.

Keywords: clean mining technology; underground disposal of waste rock; centralized sorting system; gob-side entry driving with preset packwall; no-pillar filling mining

W przedsiębiorstwach górnictwa węglowego wciąż trwają prace nad opracowaniem czystej technologii i metod wydobycia, z poszanowaniem zasad zrównoważonego rozwoju, szczególnie zaś w kontekście restrukturyzacji chińskiego rynku dostawców węgla. Pozostawianie w kopalniach podziemnych skał odpadowych jest poważnym zagadnieniem w aspekcie czystych technologii wydobycia surowców mineralnych.

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Wychodząc w rozważaniach od podstawowych przyczyn i problemów związanych z gospodarką odpadami i dążeniem do opracowania metod wydobycia bardziej przyjaznych dla środowiska, w pierwszej części artykułu omówiono warunki górnicze i techniczne dla wydobycia w kopalni węgla Gaozhuang, przeanalizowano główne źródła powstawania odpadów skalnych pod ziemią i zaproponowano metodę polegającą na wypełnianiu pustek w podziemnych zrobach, z wykorzystaniem skał odpadowych jako głównego składnika agregatu do produkcji betonu. Przeanalizowano także ilości pozyskiwanych skał w zależności od lokalizacji w obrębie kopalni oraz przewidywane wykorzystanie skał odpadowych. Ustanowiono scentralizowany system sortowania skał odpadowych, tak by zapewnić ich efektywne przemieszczenie uwzględniając ograniczenia związane z wydajnością urządzeń wyciągowych. Na tej podstawie, poprzez wykorzystanie skał odpadowych jako głównego składnika agregatu dla betonu, opracowano nowatorską technologię prowadzenia chodnika w zrobach z pasem podsadzkowym. Ta nowoczesna technologia zwiększa zakres możliwości ponownego wykorzystanie zasobów, rozwiązuje problem utylizacji skał odpadowych umożliwiając czyste wydobycie, dając w efekcie znaczne korzyści finansowe i społeczne. Ponadto, wyniki badań dostarczyły danych do opracowania teoretycznych wytycznych do opracowania czystej metody wydobycia do wykorzystania także w innych kopalniach węgla.

Słowa kluczowe: czyste metody wydobycia, podziemna likwidacja skał odpadowych, scentralizowany system sortowania, prowadzenia chodnika w zrobach z pasem podsadzkowym, wypełnianie pustek poza filarami

1. Introduction

There is no doubt that the proportion of coal consumption in primary energy consumption will gradually reduce someday, but for a long period of time, coal will continue to be the main source of energy in China (You & Xu, 2010; Wang et al., 2011; Wang & Li, 2016). Therefore, it is of great strategic significance to build an intensive, safe, efficient, green and modern coal industry system to supplement China's energy resources and promote the healthy and stable development of the society and economy. As a kind of fossil energy, coal can not only make a significant contribution to human civilization and social progress, but can also cause serious ecological damage to the mining areas (Bell et al., 2001; Kuenzer et al., 2007; Mishra et al., 2008; Bian et al., 2010), such as surface subsidence caused by coal mining, destruction of the groundwater cycling system, and environmental pollution caused by the wastes. The delicate balance between efficient coal mining and ecological constraints has attracted governmental attention. For example, the "Outline of the 13th Five-Year Plan (2016-2020) for National Economic and Social Development of the People's Republic of China" clearly puts forward that China should "...utilize coal energy cleanly and efficiently, limit the development in the eastern regions, control the situation in central and northeast regions, optimize the exploitation of coal resources in the western regions, and promote the technologies of large-scale coal-based green mining and transforming..." (Zhang, 2016). Further, the "13th Five-Year Plan (2016-2020) for Coal Industry Development" emphasizes that the industry should "...establish the concept of green development, push green mining of coal resources, develop washing and processing of raw coal, enhance circular economy, strengthen ecological management in mining areas, and promote the revolution of coal supply..." (Song et al., 2007). Additionally, with regard to "green mining", the plan goes on to say that the industry should "...promote the technologies of filling mining, aquifer-protective mining, coal & gas co-mining, mining with non-welling waste rock in coal mines...". On the basis of these plans, clean mining of coal resources can be defined (Wang & Gui, 2001; Hilson 2003; Pu, 2010; Chen & Xu, 2010; Goswami, 2013): During the process of mining high-quality coal, comprehensive measures are taken to minimize environmental pollution. Under the background of structural reform of China's coal industry supply side, it has been an inevitable choice for coal enterprises to vigorously develop clean mining technologies for the sake of sustainable development (Zhou & Zhao, 2016).

The technology to deal with non-welling waste rock is one of the important aspects of clean mining of coal resources. Waste rock comprises a large proportion of the industrial solid wastes from emissions of coal mines (Bian, 2007), and the hillock has now become a unique symbol of China's coal mines. As of 2010, there are more than 1700 hillocks existing in large coal mines in China, with a combined weight of over 4.5 billion tons, occupying a land area of about 150 km^2 (Bian et al., 2009; Zhang et al., 2009; Liu & Liu, 2010). By the end of the thirteenth five-year plan (2020), the weight of waste rock is expected to be increased by 56 million tons in the eastern regions, 336 million tons in the central and northeastern regions, and 403 million tons in the western regions. Pyramidal hillocks on the ground have a huge impact on the environment, society and economy of the mining areas (Szczepanska & Twardowska, 1999; Querol et al., 2008; Jiang et al., 2014). For example, hillocks can encroach on cultivated land, emit harmful gases such as SO_2, and cause toxic heavy metals to penetrate into the soil and damage water quality. Additionally, some hillocks may also be in danger of collapsing and exploding (Dong et al., 2007; Pan et al., 2009), threatening safety and property. At present, disposal and utilization of waste rock are mostly reprocessed, i.e., treatment after pollution. However, the problem of the disposal of waste rock has not been solved from the root, which means that coal mining and environmental protection cannot be accomplished at the same time (Li & Han, 2006; Li et al., 2006; Liu et al., 2010; Franks et al., 2011). Clean mining technology is primarily preventative in nature. Based on specific conditions of mines, techniques include reducing emission of waste rock from the root and leaving waste rock underground can finally realize clean mining of coal resources (Zhang et al., 2004).

Therefore, in order to mitigate the disadvantages of reprocessing disposal of waste rock, this study begins from the mining technical conditions of Gaozhuang Coal Mine (GCM), analyzes the main source of underground waste rock, puts forth the methods of "filling underground abandoned roadways" and "acting as main aggregate of concrete" based on different output locations and subsequent functions of the waste rock, and establishes the centralized sorting system of underground waste rock, effectively easing the mine hoisting capacity limitations. On this basis, through utilizing waste rock as the main aggregate of concrete, a novel technology of gob-side entry driving with preset packwall has been developed. This technology improves the recycling rate of underground coal resources, solves the waste rock disposal problem, makes clean mining possible, and achieves significant economic and social benefits. Now, the similar technology has been applied in some coal-producing countries, such as America, Australia, India, Russia, Indonesia and Germany.

2. Mine overview and mining technical conditions

2.1. Mine overview

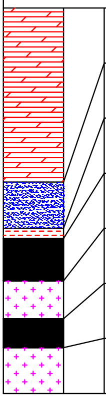
GCM is one of the main coal mines of the Zaozhuang Mining Group in China. It is located in the southwest of Tengnan coalfield, while the headframe of main shaft is located in Weishan county, Shandong province. The length of GCM is 8.5 km from north to south, and the width is

2.5 to 5.5 km from east to west, covering a total area of 32 km^2. The mine surface is actually the alluvial plain of Binhu, dipping slowly from northwest to southeast, and the ground elevation is +33 to +34 meters. GCM was put into production in 1997, with an original producing capacity of 900,000 t/a. After several technological improvements, the current producing capacity is 3.5 million t/a. The remaining service life of the mine is approximately 26 years. It is mined vertically with multi levels, and a centralized appose exhaust ventilation is used. The main mining level of the mine is –430 m, and the western fifth mining district (WFMD) is only available, mining #3$_{up}$ and #3$_{down}$ coal seams.

2.2. Mining technical conditions

The WFMD of GCM is designed to be a double-wing mining district, with a total of three down-dip entries (air-reclaiming entry, track entry and transportation entry) serving for #3$_{up}$ and #3$_{down}$ coal seams. The mining district is excavated from top to bottom. The upper district sublevel entry is the tailgate and the lower district sublevel entry is the headgate. The thickness of the #3$_{up}$ coal seam is 3.75 to 6.20 m and the average thickness is 5.20 m. The inclination of the coal seam is 13° to 21° and the average value is approximately 17°. The structure of the coal seam is stable and the density of the whole layer is 1.35 t/m^3 approximately. The roof above the #3$_{up}$ coal seam is comprised primarily of mudstone and sandstone and the floor below the #3$_{up}$ coal seam is dominated by siltstone.

The #3$_{up}$509 coalface is the deepest coalface among the WFMD, with a strike length of 1180 m, an inclined length of 220 m, and a total mining area of 259600 m^2. The corresponding ground elevation is +32.76 to +33.70 m, and the underground elevation is –244.6 to –414.0 m. The #3$_{up}$509 coalface is adjacent to the south of the #3$_{up}$507 coalface (which has been mined out) and expands -600 level to the north. This coalface is adjacent to the Shaoji Fault on the east and the down-dip entries on the west. An inclined longwall fully-mechanized mining method has been used to cut the height (5.0±0.1 m) of the #3$_{up}$ coal seam, and a kind of all-collapse method is used to manage the goaf roof. Fig. 1 shows the stratigraphic column of #3$_{up}$509 coalface.



Column	Lithology	Thickness/m	Remarks
1	Gritstone	77.0	/
2	Packsand	10.4	Main roof
3	Mudstone	0.3	Immediate roof
4	Coal	5.2	#3$_{up}$ coal seam
5	Siltstone	4.4	Immediate floor
6	Coal	3.8	#3$_{down}$ coal seam
7	Siltstone	9.6	/

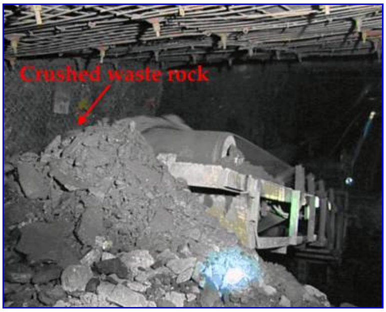
Fig. 1. Stratigraphic column of #3$_{up}$509 coalface

3. Source and classification of underground waste rock

In most coal mines, underground waste rock is mainly derived from the excavation of roadways, although some is also contained in coal seams and roofs (Zhou et al., 2014). The waste rock discharged from the underground production of GCM is mainly derived from the excavation of development roadways, the bottom coal bunker and the slipping coal hole, as well as waste rock generated during the mining process of the coalface (including waste rock mixed into raw coal in the roof and contained in the fault areas). This mine annually produces approximately 300,000 tons of waste rock. In view of the mining technical conditions of GCM, two kinds of disposal schemes are put forward based on different output locations and subsequent functions of waste rock:

(1) Waste rock that is generated during the process of excavating roadways (–600 level development), bottom coal bunker (a sub coal bunker of main shaft), slipping coal hole (down-dip entry in WFMD), and other excavation process will be transported to the waste disposal site to be crushed through the conveyor belt or side-unloading truck. It can then be recycled to directly fill the underground abandoned roadways, as shown in Fig. 2(a).

(2) Waste rock that is generated during the mining process of underground coalface (such as the $\#3_{up}509$ coalface) will be transported to the centralized sorting system together with coal through the conveyor belt of the district sublevel entry. Through the centralized sorting system, the waste rock will be crushed and then transported to the no-pillar filling mining zone. There, it will serve as the main aggregate to be mixed with other materials, as shown in Fig. 2(b).



(a) Filling underground abandoned roadways

(b) Transporting to no-pillar filling mining zone

Fig. 2. Disposal schemes of underground waste rock

4. Centralized sorting system of underground waste rock

4.1. Necessity of establishment

Since May 2005, the mining system of GCM changed from the original hydraulic and dry co-mining system (hydraulic mining and large-cutting-height mining) into the single dry mining system. Because the western first and third mining districts have been mined completely and the western seventh mining district is under construction, the WFMD is only available mining district. In accordance with the production plans of the Group, GCM had been required to produce more than 3.5 million tons of raw coal in 2008. To realize this goal, at least two coalfaces must constantly have been working (completely concentrated in the WFMD). In addition, a sub coal bunker of main shaft was constructed in 2006, alleviating the lifting pressure to some extent. However, the fundamental transportation problem still has not been solved. At present, the maximum lifting capacity of the main shaft skip is 3.7 million t/a, and the capacity of a single skip has increased to 9.5 t. However, if we want to further increase skip capacity, the main hoist, derrick and cage guide must be stopped and redesigned, which is definitely unrealistic. Therefore, in order to ensure the reliability of the capacity of the main shaft and the mine's annual production tasks, it is necessary to establish a set of centralized sorting system to sort out large waste rock, maximizing the amount of clean coal.

4.2. Schemes design

(1) Schemes design

Three design schemes are put forward in terms of the location of the centralized sorting system, on the basis of the lifting system and loading-unloading mode of main shaft in GCM.

Scheme one: A centralized sorting system is established in the coal bunker area in the WFMD. The total excavation length of the roadway is approximately 400 m, the depth of the waste rock bunker is 25 m and the diameter is 6 m. This project will take 3 months to complete if the two-heads-excavating speed is 70 m per month.

Scheme two: A centralized sorting system is established in the coal bunker area in the western eleventh mining district. The total excavation length of the roadway is approximately 500 m, the depth of the slipping coal hole is 20 m and the diameter is 2 m, while the depth of the waste rock bunker is 25 m and the diameter is 6 m. This project will take 4 months to complete if the two-heads-excavating speed is 70 m per month.

Scheme three: A centralized sorting system is established in the coal bunker of main shaft. The total excavation length of the roadway is approximately 656 m, while the length of expanding rib is about 105 m. The depth of the #1 waste rock bunker is 30 m and the diameter is 6 m; the depth of the #2 waste rock bunker is 40 m and the diameter is 6 m. This project will take 6.5 months to complete if the two-heads-excavating speed is 70 m per month.

(2) Schemes Comparison

Scheme one: 1) Advantages: The system is simple and reliable. The workload is minimal. Waste rock can be sorted out at the maximum speed. 2) Disadvantages: The workload of transportation is larger, which has an impact on the entire transportation system of the mine.

Scheme two: 1) Advantages: The system is simple and the cross section is relatively small. 2) Disadvantages: Heavy loading of construction, and long construction period; The whole mine will be affected by the process of constructing slipping coal hole; The workload of transportation is larger, which has an impact on the entire transportation system of the mine.

Scheme three: 1) Advantages: The system is reliable and able to transport waste rock rapidly with conveyor belts, which has no impact on the transportation system of the mine. 2) Disadvantages: The large workload and long construction period decrease the likelihood of implementation.

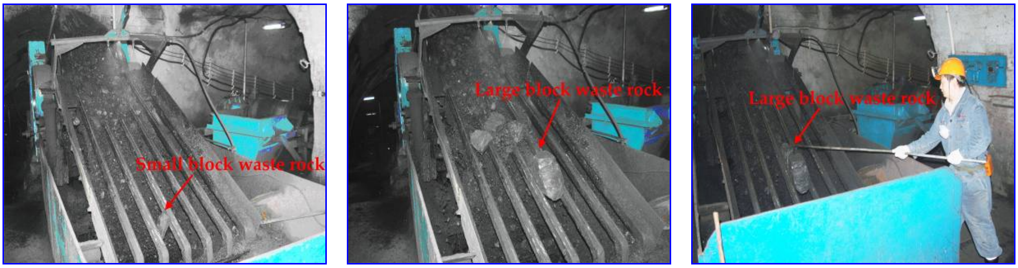
Considering the actual producing situation of GCM and the advantages and disadvantages of the above three design schemes, it can be seen that scheme one is the most economical and reliable, as the system is simple and easy to build quickly. Therefore, scheme one is chosen as the final construction scheme of a centralized sorting system.

4.3. Application effect

(1) Process flow

There are three steps in the centralized sorting system process flow.

Screening: The mixture of coal and waste rock is transported to the centralized sorting system by the conveyor belt. Preliminary screening is carried out to separate the small block waste rock from the coal, while the large block waste rock will be transported to the next flow. The screening process is shown in Fig. 3.



(a) Small block waste rock through sieve (b) Large block waste rock through sieve (c) Worker deal with large block waste rock

Fig. 3. Screening process

Sorting: When large pieces of coal and waste rock are separated during the screening process, underground workers will sort out the large block waste rock from sorting conveyor belt (SCB) and put this waste rock into the iron funnel beside them. Then, this large block waste rock will be slipped into the lower side-unloading truck for transportation to the waste rock disposal site. There, it will be crushed and used in the no-pillar filling mining zone. Meanwhile, the coal on the SCB will be transported to the gathering conveyor belt (GCB) through a leaking funnel. The sorting process is shown in Fig. 4.

Gathering: The coal from the SCB will be transported to transportation entry of the WFMD by the GCB and then be transported to outside. The gathering process is shown in Fig. 5.

(a) Workers sort out large block waste rock (b) Large block waste rock is put into the iron funnel

Fig. 4. Sorting process

(a) Coal fromSCB to GCB (b) Transporting coal to transportation entry

Fig. 5. Gathering process

(2) Application effect

The centralized sorting system in GCM was completed by the end of 2007 and officially put into use in early 2008. Based on the feedback from the usage of this centralized sorting system so far, it is clear that this system has alleviated the mine hoisting capacity limitations. In addition, this system has eliminated the problem of waste rock stuck in bunker. This ensures the continuity and reliability of the system operation, resulting in very significant economic benefits with little investment. For example, after the operation of the system, the main shaft will increase its raw coal hoisting by approximately 500 tons per day. Calculated by 300 working days per year, the result will be 150,000 more tons of raw coal produced every year. Assuming a market price of raw coal of 500 CNY per ton, this scheme will result in an extra output value of about 75 million CNY annually.

5. A novel technology of gob-side entry driving with preset packwall

At present, coal pillars (3-30 m) are still retained in the adjacent coalfaces in most mines in China. The purpose of these pillars is to protect the in-use coalface (or preparative coalface) and its adjacent goaf from spontaneous combustion due to air leakage and to reduce the impact of lateral support pressure on the coalface. In recent years, in order to reduce the loss of coal resources caused by setting coal pillars of district sublevel, the technology of gob-side entry driving with narrow coal pillars (3-6 m) has been developed based on the strata pressure behavior law of the coalface (Fan et al., 2014; Zhang et al., 2014). However, the problem of the coal resources loss (approximately 2% to 3%) has not been solved by this technology, and the remaining coal pillar in the goaf is easy to collapse, resulting in spontaneous combustion of mined areas and posing a great threat to safety (Zhang et al., 2013). In particular, there is a large demand for ventilation in large-mining-height coalfaces or top coal caving coalfaces. Therefore, the cross section of the gateways must be large enough, which may be greater affected by the strata pressure. For these reasons, narrow coal pillars are not suitable (Yan et al., 2013). Therefore, based on the mining technical conditions of $\#3_{up}509$ coalface in GCM, gob-side entry driving with preset packwall has been developed by using the waste rock as the main aggregate of concrete, improving the recycling rate of coal resources and ensuring the safety of the coalface.

5.1. Technical steps of gob-side entry driving with preset packwall

The technical steps of this novel technology are as follows:

Step 1: When arranging the coalface of upper district sublevel, excavate the headgate with a large cross-section (reserved zone for preset packwall) (see Fig. 6(a)) and preset a packwall on the tailgate in the coalface of lower district sublevel along the headgate in the coalface of upper district sublevel (see Fig. 6(b));

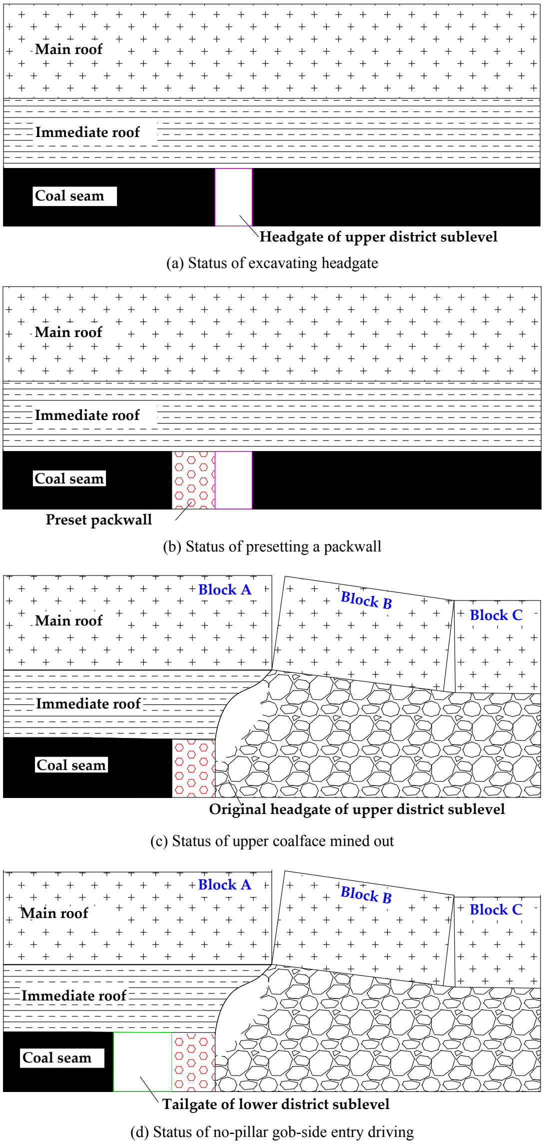


Fig. 6. Technical steps of the novel technology

Step 2: After the coalface of upper district sublevel has been completely mined, wait for the surrounding structure to stabilize (see Fig. 6(c)). Then, excavate the tailgate in the coalface of lower district sublevel close to the preset packwall without setting coal pillars (see Fig. 6(d)). This process accomplishes no-pillar gob-side entry driving.

5.2. Material composition and structure parameters of preset packwall

(1) Material composition

The material of the preset packwall is the waste rock slag concrete (cementing materials based on water and waste rock slag, and mixed with the appropriate amount of fly ash aggregate) belonging to the series of light-aggregate concrete. Because a concrete pump must be used to deliver waste rock slag concrete during the filling process, the waste rock slag concrete should be non-dispersed, non-segregated and low-bleeding. MT-3 cemented material has the following characteristics: 1) Low saturated water absorption; 2) High mobility; 3) High-intensity quick-setting; and 4) Good bending resistance. Therefore, MT-3 cemented material has been chosen as the waste rock slag concrete binder.

Considering the hardness of the coal seam, the width of the preset packwall (as narrow as possible), the advanced speed of the large-mining-height coalface, and the strength loss during the concrete transportation process, a final plan has been decided: the width of the preset packwall should not be less than 1.5 m; the concrete grade of the waste rock slag should be CL25; the design compressive strength is 18 MPa; and the design density is 2130 kg/m^3. Therefore, 1000 kg of waste rock slag (diameter 3-5 mm), 200 kg of fly ash, 500 kg of MT-3 cementing material and 430 kg of water are needed per cubic meter of concrete.

(2) Structure parameters

Considering the allowable time of the underground test, the cross-section size (width × height = 3.8 m×3.5 m) of the tailgate of #3$_{up}$509 coalface, the cross-section size (width × height = 3.8 m×2.7 m) of the headgate of #3$_{up}$507 coalface, the high pressure resistance and stability of preset packwall, the possibility of air leakage between the upper and lower district sublevels and other factors, the specifications of the preset packwall have been decided as follows: The height of the zone (up to the headgate of #3$_{up}$507 coalface and down to the coal floor of #3$_{up}$ coal seam) is 4.0 m and the width is 1.6 m, leaving an amount of top coal with a thickness of 1.1 m. Also, a gap of 0.1 m is to be reserved between preset packwall and top coal. The structural cross-section parameters of preset packwall are shown in Fig. 7.

5.3. Site construction process

(1) Expanding rib of headgate in #3$_{up}$507 coalface

The expanding rib work started from the front of the #3$_{up}$507 coalface by drilling and blasting. The area was excavated from the outside to the inside section by section along the headgate, and on the basis of the existing cross-section, the cross-section was expanded towards the #3$_{up}$509 coalface according to the design width (1.6 m) of the preset packwall. After finishing the expanding rib work, the roof was supported with anchor bolt-beam-mesh-cable and the expanding rib side was supported with bamboo anchor bolts, with the specific support parameters remaining

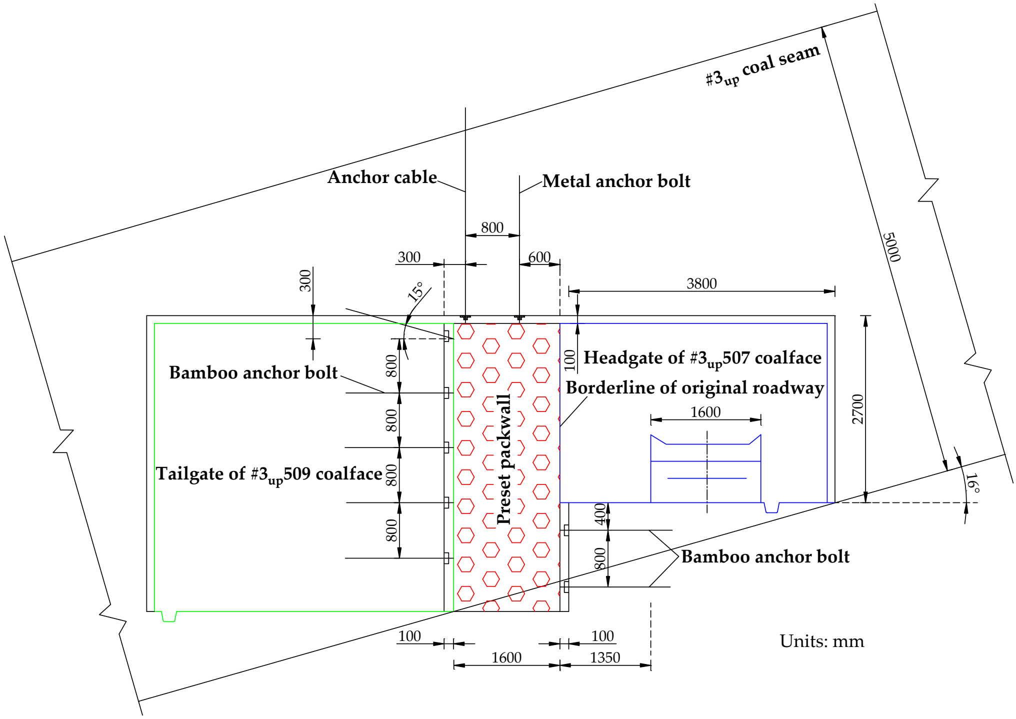


Fig. 7. Structural cross-section parameters of preset packwall

consistent with the original parameters. Props with a space of 1 m were established in the outside of the preset packwall together with the expanding rib.

(2) Construction of preset packwall

After the expansion of the headgate in #3_{up}507 coalface has been completed, the construction of preset packwall can be started from the bottom of #3_{up}509 coalface to top side, section by section. The bottom area of the headgate in the #3_{up}507 coalface should be filled first. Then, the fixed shuttering is settled along the outside of preset packwall. Finally, the remaining space is filled. Fig. 8 shows the site construction process, and the site construction effect is shown in Fig. 9.

(3) Excavation of tailgate in #3_{up}509 coalface

After the construction of the preset packwall in #3_{up}507 coalface has finished, and when the structure of the surrounding rock is stable, the excavation of the tailgate in #3_{up}507 coalface can be initiated following the preset packwall. The cross-section shape of the tailgate in #3_{up}509 coalface is rectangular, with an anchor bolt-beam-mesh-cable as a combined support (shown in Fig. 10). The main support parameters are as follows:

1) Roof support: The specifications of the roof metal screw anchor bolt are 20 mm × 2200 mm (diameter × length) with a spacing of 800 mm × 800 mm; the anchor bolt tray is a square-shaped steel plate, with specifications of 200 mm × 200 mm × 10 mm (length × width × thickness); the roof anchor cable is made by 7 strand high-strength steel wire (diameter is 5 mm), made in the three-eyes arrangement, and the length of the anchor point inside the stable roof of the #3_{up} coal seam is not less than 2000 mm; the

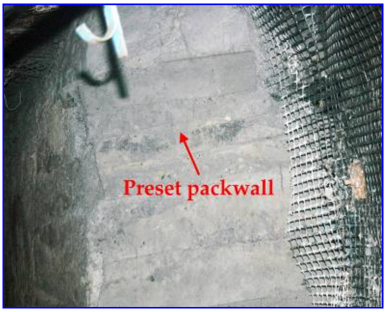
(a) Unloading

(b) Mixing

(c) Delivery

(b) Filling

Fig. 8. Site construction process



(a) Cross-section of preset packwall

(b) Side of preset packwall

Fig. 9. Site construction effect

anchor cable tray is made from #12 channel steel with a length of 250 mm; the anchor cable plate is a square-shaped steel plate, with specifications of 50 mm × 50 mm × 8 mm (length × width × thickness). The diameter of the steel bar of the steel ladder beam is 16 mm, and the specifications of steel ladder beam are 3600 mm × 90 mm (length × width), with a spacing of 800 mm. Diamond metal mesh was weaved with #8 iron wire, and the specifications are 4400 mm × 1000 mm (length × width).

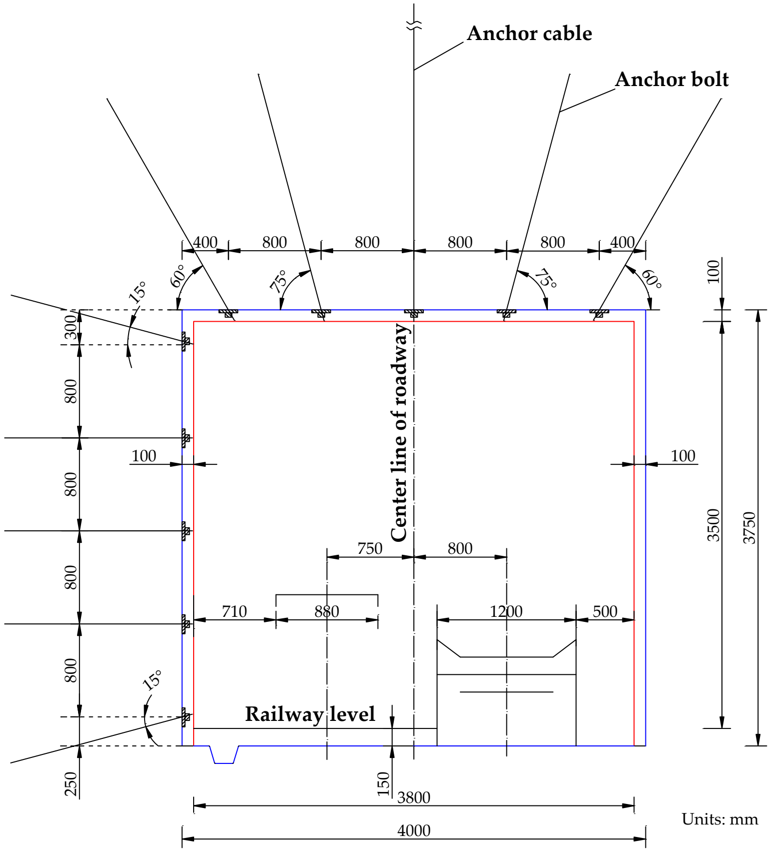


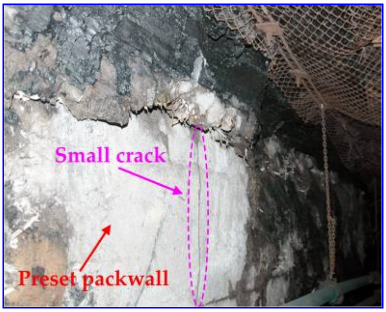
Fig. 10. Support parameters of tailgate in #3_{up}509 coalface

2) Two sides support: The specifications of the ordinary metal bolt on both sides is 16 mm × 1650 mm (diameter × length), with a spacing of 800 mm × 800 mm; the anchor bolt tray is made by the same ordinary metal, and its specifications are 200 mm × 200 mm × 10 mm (length × width × thickness). Diamond metal mesh was weaved with #8 iron wire, and the specifications are 3500 mm×1000 mm (length × width).

5.4. Engineering application effect

At present, the #3_{up}507 coalface and the #3_{up}509 coalface of GCM have both been completely mined by normal methods. From the view of site engineering application, the preset packwall is basically intact (shown in Fig. 11) except one small crack from the roof of the roadway to the floor that undergoes two-times repeated mining processes. With the help of the novel technology, the loss of coal resources has been greatly reduced, the remaining service life of the mine has been prolonged, and the risk of spontaneous combustion of coal pillars has been reduced. Moreover, by the usage of underground waste rock in the mine, real technical and economic benefits have been achieved (increasing output value approximately 10 million CNY).

(a) Side view of #3_{up}507 coalface



(b) Side view of#3_{up}509 coalface

Fig. 11. Engineering application effect

6. Conclusions

(1) The underground waste rock of GCM is mainly derived from the excavation of the development roadways, the bottom coal bunker and the slipping coal hole. Two kinds of disposal schemes are put forward based on different output locations and subsequent functions of waste rock, namely "filling underground abandoned zone" and "acting as main aggregate of concrete".

(2) The centralized sorting system process flow consists of three main steps: screening, sorting and gathering. When this centralized sorting system is successfully implemented, it greatly alleviates the mine hoisting capacity limitations and makes a very significant economic benefit with little investment (estimated additional annual output value of 75 million CNY). In addition, this system lays a foundation for the early stages of successful underground clean mining.

(3) Gob-side entry driving with preset packwall has been developed by using the waste rock as the main aggregate of concrete. This method overcomes the shortcomings of traditional gob-side entry driving method, improves the recycling rate of coal resources, solves the waste rock disposal problem, makes underground clean mining possible, and achieves great economic and social benefits. At the same time, the results of this study have provided theoretical guidance about clean mining technology for other coal mines in China, e.g., Fucun Coal Mine, Xin'an Coal Mine, Xuchang Coal Mine, and so on.

Acknowledgments

The research is financially supported by the Fundamental Research Funds for the Central Universities (No. 2017XKQY022). We wish to thank the GCM for supporting to conduct this important study. Special thanks are given to Mapletrans Company in Wuhan, China, for its professional English editing service. The authors are also grateful to the anonymous reviewers for their constructive comments and helpful suggestions.

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