

Application and Development on Coal Mine Backfill Mining Technologies in China

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Abstract—The rapid development of backfill mining technologies were reviewed in Chinese coal mines from the 2002 to 2012 in Chinese coal mines. Some field engineering applications were introduced, the main data was collected from 27 typical backfill mining working face, including geology survey, mining setting, backfill material, technique system and monitoring effects etc. The main technologies include roadway gangue backfilling, conventional gangue backfilling, fully-mechanized gangue compacting backfilling, pneumatic backfilling, paste or paste-like backfilling, slurry or slurry-like backfilling etc. Roadway backfilling is suitable to protect the important buildings. Pneumatic backfilling, conventional mining backfilling, fully-mechanized mining compacting backfilling, paste or paste-like backfilling are suitable for the large regional operations to protect the general or important buildings and structures. Slurry or slurry-like backfilling are suitable for the operations with the single thin coal seam or the lack of backfilling materials. Some backfill indexes, including capital investment, backfill capacity, production, backfill cost per ton, mechanized level, system stability, backfill deformation, surface subsidence coefficient etc. were used to evaluate field engineering application effects. Ground subsidence software was developed to predict the ground movement parameters by Shandong University of Science and Technology based on field measured data. The future backfill development direction of backfill technology was analyzed. The paper provided an important reference, which will have an significance to promote and use the backfill mining technologies.

Keywords—coal mine, solid waste, roadway throwing backfilling, pneumatic pipeline backfilling, conventional throwing backfilling, fully-mechanized tamping backfilling, paste or paste-like backfilling, slurry or slurry-like backfilling, ground subsidence control, surface movement parameters

I. THE INTRODUCTION

China is a country rich on coal, but poor on oil and gas (Wang 2010; Wang 2012). With the rapid economic development, the exploitation and utilization of coal resources are becoming more and more important for the country. Coal resources excavated under buildings, railways, water bodies and above confined water have been a major concern (Hao 2012; Yu et al. 2010). In order to solve a series of mining-induced social and environmental problems mentioned above, and those related to solid waste discharge

and mining subsidence (Qian 2003; Zhu 2005; Luo 2008), all kinds of backfill technologies have been tried in the coal mines in central eastern part of China. According to an incomplete statistic, recoverable reserves under buildings, railways, water body and above confined water accounts for more than 13.79 billion tons, coal gangue rejects had accumulated more than 4.5 billion tons, and the total coal fly ash accumulation had been more than 800 million tons. In addition, the mining-induced land damage was more than 34 thousand hectares annually, and the total area of surface subsidence was more than 500 thousand hectares. Natural environment had become vulnerable from increasing amounting of waste, which had been a major polluting source. Hence, it had been an urgent technical problem to maximize the resource utilization, optimize solid wastes disposal and minimize mining-induced damage in a scientifically sound and socially responsible way (Zhang 2008; Guo et al. 2005).

Due to its significant benefit in mining safety, recovery ratio, and environment, mining backfill technologies have been an important component in the underground stope mining. Numerous studies had been done in the past few decades especially in the non-coal mines. The experience of mining backfill technology in the past decades, illustrated that the properties of binder and the grade of tailings played a significant role in the mechanical properties of fill body (Yao 2012). The geotechnical properties of cemented paste backfill were investigated in Canningt Mine of Australia (Rankine et al 2007). The Saturated hydraulic conductivity of cemented paste backfill was conducted (Fall 2009). The building damages of paste backfill mining under villages was analyzed (Chai 2011). Numerical simulation and mechanism analysis of backfill material were conducted in coalmine (Hu 2010). Physical-chemical and mechanical characteristics of consolidated and unconsolidated cemented paste backfills were studied (Yilmaz 2013). Mix proportioning of underground cemented tailings backfill was conducted (Fall et al. 2008). The use of paste backfill technology as a ground support method in cut-and-fill mines was reviewed (Belem and Benzaazoua 2004). The paste backfill technology in underground mine was designed and used (Belem and Benzaazoua 2008). The differences in underground mines dewatering with the application of caving or backfilling mining methods were analyzed (Swaskraba and Abel 1994).

The engineering design of paste backfill systems was proposed (Dirige 2003). The preparation and transportation of paste backfill were presented (Newman 1992). In situ measurements of cemented paste backfill at the Cayeli Mine was conducted (Thompson 2012). Overlying strata movement characteristics in fully mechanized coal mining and backfilling long-wall face by physical model simulation were studied (Huang et al. 2011). Backfilling technology and strata behaviors in fully mechanized coal mining working face were reported (Zhang et al. 2012).

These studies had contributed to the improvement of the backfill mining technologies in the recent decades, however, most of research results mainly focused on non-coal mines. Due to the difference of deposition shape and methods used for mining coal seam and metal ore body, it is very useful to understand and evaluate application experience of main backfill mining technologies used in the central eastern coal mines in China. The paper presents the key case studies where geological and mining conditions, backfill methods, technology characteristics, evaluation indexes, strata movement parameters etc. are investigated. Those case studies illustrate the main issues, application conditions and future development directions of all kinds of backfill mining technologies in coal mines.

II. BACKFILL MINING METHODS AND APPLICATION EXAMPLES

For coal mines, the backfill mining is a relatively new mining method which uses solid wastes from the vicinity of coal mine such as coal gangue, fly ash, slag, poor quality soil, river sand, urban solid waste etc. to fill the goaf and prevent the overlying strata fall. At present, there are three kinds of backfill mining methods, the backfill materials are composed of raw gangue or mixes of fly ash, Portland cement and water which has certain solid concentration, such as paste or like-paste material. The paste material has a significant characteristic which is not constrained by critical velocity and dehydration in the pipeline and can be transported by pipe with the help of pump or gravity. The purpose of backfill mining is to fill the stope void space timely and utilize backfill body to limit the overlying strata movement and surface subsidence and hence protect buildings, underwater resources, ecological environment and so on. In the past decade, various backfill mining technologies have been carried out in the central eastern coal mines in China. According to geological mining condition, backfill materials, transportation methods, backfill purposes and backfill technology, the paper summarizes and evaluates the main application examples of backfill mining as shown in Table 1.

Table 1 Backfill mining examples in China

No	Mine, location	backfill technique	Coal recovery type	Coal seam Thickness/m	Comments
1	Xingdong mine, Jizhong	Roadway throwing gangue backfilling	Under industry square	3.5	Primary gangue
2	Dongshan mine, Tanyuan	Roadway throwing gangue backfilling	Under buildings	6.5	Primary gangue
3	Xuchang mine, Zibo	Roadway throwing gangue backfilling	Under buildings of strips pillar	4.9	Primary gangue
4	Gaozhuang mine, Zaozhuang	Roadway excavated and gangue cement paste	Under buildings and lake	4-6	Primary gangue and cement paste
5	Quangou mine, Xinwen	Conventional throwing gangue backfilling	Under buildings	1.7	Crushed gangue
6	Ezhuang mine, Xinwen	Conventional throwing gangue backfilling	Under buildings	1.0-2.1	Primary gangue
7	Panxi mine, Xinwen	Conventional throwing gangue backfilling	Disposed gangue	2.2	Primary gangue
8	Xiezhuang mine, Xinwen	Fully-mechanized tamping gangue backfilling	Gangue disposed	1.53	Primary gangue
9	Zhaizhen mine, Xinwen	Fully-mechanized tamping gangue backfilling	Under buildings	1.5-3.0	Compacting fill
10	Huayuan mine, Jining	Fully-mechanized tamping gangue backfilling	Under buildings, railway and water body	2.0	Compacting fill
11	Tangshan mine, Kailuan	Fully-mechanized tamping gangue backfilling	Under buildings	2.0-3.0	Compacting fill
12	Wugou mine, Hengyuan	Fully-mechanized tamping gangue backfilling	On the confined water	3.1	Compacting fill to improve upper limit
13	Pingmei mine, Shenma	Fully-mechanized tamping gangue backfilling	Under industry square	3.3	Compacting fill
14	Jisan mine, Yanzhou	Fully-mechanized tamping gangue backfilling	Under rivers	3.5	Compacting fill
15	Xingtai mine, Jizhong	Fully-mechanized tamping gangue backfilling	Under buildings	2.5-3.0	Compacting fill and grouting
16	Suncun mine, Xinwen	Paste-like backfilling	Under industrial square	2.1	Gravity self-flow
17	Beixu mine, Yanzhou	Paste-like backfilling	Under buildings	0.7-1.2	Pumping and pipe
18	Caozhuang mine, Feicheng	Paste-like backfilling	On the confined water	1.9-2.0	Gravity self-flow
19	Jisuo mine, Tengzhou	Paste-like backfilling	Under buildings	0.98-1.4	Gravity self-flow
20	Tongshun mine, Fengfeng	Paste-like backfilling	Under buildings	2.6	Gravity self-flow
21	Taiping mine, Jining	Paste backfilling	Under buildings, river and water body	2.2	Pumping pipe, slice mining
22	Daizhuang mine, Zibo	Paste backfilling	Under buildings of coal pillar	2.5-2.9	Pumping pipeline

23	Yangdong mine, Fengeng	Paste backfilling	Under buildings	2.8(5.6)	Pumping pipeline, slice mining
24	Xiaotun mine, Fengfeng	Paste backfilling	Under buildings	2.7	Pumping pipeline, slice mining
25	Wangzhuang mine, Zibo	Slurry backfilling	Under buildings	0.95-1.83	gravity self-flow
26	Bucun mine, Zibo	Slurry backfilling	Under buildings and confined water	1.2	gravity self-flow
27	Tianzhuang mine, Linyi	Slurry-like backfilling	Under buildings	1.2	Pumping pipe
28	Taoyi mine, Jizhong	Slurry-like backfilling	Under buildings	3.9	Pumping pipeline, specific bags

A. The roadway mining and gangue backfill technology

The technology is aiming at the extraction of coal pillar, isolated coal resource, or areas under surface mining facilities. The main equipments used are the roadheader and gangue casting machine. Generally the roadway was excavated in the residual coal area and supported by the bolts and metal meshes. When one roadway is excavated completely, the gangues are casted into the roadway to fill the empty voids immediately by the gangue casting machine. In order to maximize the extraction of resources safely, the place-changing mining method is used and coal pillars are reserved between two roadways and the recovery ratio is normally less than 50%. One of examples of such mining method is the Xingdong coal mine, Xingdong coal mine is located in the suburban district of Xingtai City, and gangue waste is not allowed to be deposited on the surface. Hence, the coal resource under surface mining facilities (or named Industrial Square) was selected as the testing area for backfilling mining. The testing area was to recover 2# coal seam, which had a thickness of about 4.0 m and dip angle of approximately 10°. The thickness of quaternary alluvium soil was about from 210 m to 320m, and coal seam was at a depth of 883 m. The roadways had a width of 5.0 m, a height of 3.5 m and a length of 400 m. Bolts and metal meshes were used to support the roadway roof and sidewalls. When one roadway was excavated completely, the backfill operation was carried out immediately. The whole system included coal mining system, gangue storage system, belt transportation system and gangue casting system. The gangue casting machine is shown in Fig.1, which has the special track system allowing it to cast gangue while moving and turning in all directions. The gangue transportation capacity is 100t/h; the gangue grain size should not be more than 150mm; the conveyer belt width is 650mm and the belt speed is 8.6m/s; the casting distance is more than 6 m. The mine had excavated dozens of roadway since 2003, the roadway backfill ratio was about 80% and annual production is more than 200 thousand tons. The most prominent advantages of this operation are its low capital investment and backfill cost per ton is low and good gangue reutilization. The main disadvantages are its low automation level and low recovery ratio. The surface monitoring showed that surface facilities were stable and buildings were in good conditions after mining.



Fig.1. The gangue casting machine

B. The conventional full-mechanized long-wall mining and casting gangue backfill technology

The key characteristics of this technology are that coal is mined by the shearer machine, the single hydraulic props and metal articulated beams are used to support the roof. When the working face progresses a certain distance, a special barrier is used to separate the working face and the goaf, then the backfill machine casts gangue to the goaf to support roof. The backfill operation progresses from the inside to outside, and from low to high. Taking Shengquan coal mine 21103 working face as an example, the coal seam was at a depth of 360m with a thickness of about 2.2 m and a dip angle of approximately 10°, the working face was 50m long. Single hydraulic supports and metal articulated beams were used to support roof, the array pitch was 1.0m and prop pitch was 0.8m. The method of roof control was as follows. When the top control distance was more than 6m or 7m, the goaf was separated to 3m or 4m and the backfill machine began to fill gangue from the inside to the outside, and the single hydraulic props were moved sequentially. The whole backfill technology included gangue storage system, belt convey system and backfill system. The whole working face arrangement was shown in Fig.2. The coal seam of 2#, 11#, 13# and 15# were mined using the backfill mining method, the annual production of coal was more than 300 thousand tons.

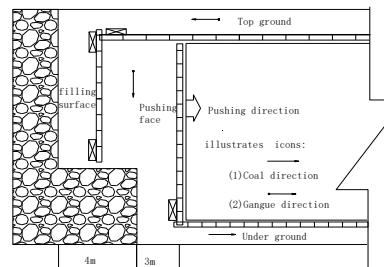


Fig.2. The whole working face arrangement of conventional fully-mechanized long-wall mining and casting gangue backfill technology

C. The low pressure pneumatic pipe backfill technology

The key feature technology is that crushed gangue is transported to the goaf by pipe with the help of the low pressure wind power generated by blowers. The whole backfill system includes gangue transportation system, crushing system, storage system, low pressure pneumatic system, and operating system. Taking Xiezhuang coal mine 31112 working face as an example, the coal seam was at a depth of 880m, had a thickness of about 2.04 m and a dip angle of approximately 26.5°, the working face was 148m long. Single hydraulic support system was used to support roof, the array pitch was 1.0m and the prop pitch was 0.8m. Backfill operation was done once the mining progressed more than 6m or 7m. The goaf was separated to 3m or 4m. The blower was the power center of backfill system, the

power of motor was 200 KW, the wind pressure was 78 KPa, the wind supply capacity was 105 m/min, the diameter was 219 mm and the wind-speed was 52 m/s. The low pressure wind pipe backfill system is shown in Fig.3. During the backfill operation carried out in Xiezhuang coal mine, the more than 25 thousand tons of filling gangue was used monthly; the annual production of coal is more than 200 thousand tons.

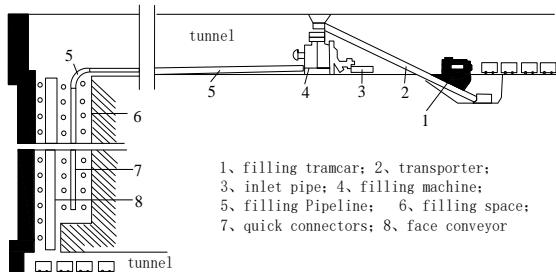


Fig.3. The low pressure wind pipe backfill system

D. The fully-mechanized longwall mining and gangue compacting backfill technology

Using this technology the rear conveyor for backfill material transportation is hanged in the fully-mechanized support tail beam, which has gates to draw the gangue easily and can be positioned at any height. In addition the system has compaction device and pushing cylinder board in the full-mechanized hydraulic support base. When operating the gangue carried by chain conveyor arrives at the goaf, the gates of rear chain conveyor begin to open from the down dip to up dip of working face, then the compaction device compact the gangue. The key technical characteristic of this technology is that it is parallel operation for the backfilling and mining, and mining and backfilling are mechanized and continuous. Taking Xingtai coal mine 7608 working face as an example, the coal seam was at a depth of 370-450m, had a thickness of about 5.6 m and a dip angle of approximately 9°. The panel has a width of 88m and length of 659m. Multi-layer fully-mechanized mining method was used. Backfill equipment includes six column self-compacting hydraulic support and chain conveyer with gates. The six column backfill self-compacting hydraulic support is shown in Fig.4. The rear chain conveyor was hanged in the hydraulic support rear beam. There were discharge gates in the middle of chute, the size was 500 mm × 400 mm and the distance of gates was 3 m. The back chain conveyor was shown in Fig.5. The whole backfill technology includes gangue crushing and feeding system, gangue storage system, belt conveying system, filling and compacting system etc. Because the backfilling and mining operations were separated, the coal productivity had been significantly improved with an annual production of more than 800 thousand tons. According to surface ground displacement monitoring results, the buildings damage was insignificant.



Fig.4. The six column filling self-compacting hydraulic support



Fig.5. The back chain conveyor

E. The gangue paste or paste-like backfill technology

Paste is the newest form of backfill material in coal mines, which is made of gangue, fly ash and a small portion of binder and water. Due to the significant advantages of paste backfill technology such as high recovery ratio, high efficiency, easy to operate, environment-friendly and good slurry stability with no segregation, no precipitation, no dehydration, easy long-distance transportation in the stops, it is an important developing direction of green mining technology in the 21st century. At present there are two types of technologies; one is called paste-like backfill technology. One key difference of two technologies is the solid concentration of slurry and the grain size distribution. The solid concentration of paste-like material is 65% to 70%, and the maximum gangue grain size is less than 5 mm. The solid concentration of paste material is 75% to 80% with the highest concentration of more than 84%, the maximum grain size is less than 25 mm. The slurry pipeline transportation method is the other difference between the two technologies. Gravity driven flow transportation is adopted in the paste-like backfill technology, whereas high pressure pump delivery is adopted in the paste technology. The whole system includes gangue crushing warehousing system, paste mixing & preparation system, pumping and pipeline delivering system and mining and isolation backfill system. Taking Daizhuang coal mine 2351 working face as an example, the coal seam was at a depth of 393 m to 502 m with an average depth of 440 m. It had a thickness of about 2.7 m and a dip angle of average approximate 6°. The panel has a width of 95 m, and length of 1074m. This panel was to mine the residual stripe coal pillar under village, the pumping and pipe delivery paste backfill technology was adopted. The slurry solid concentration was 80%. A new ZC5600/17/32 four column standing backfill hydraulic support system was used, which had the upper isolation board in the support end beam and the lower isolation board in the base. The whole system and the scene were shown in Fig. 6. The surface rock displacement monitoring showed the maximum subsidence was 194.43 mm, the subsidence coefficient was 0.07.

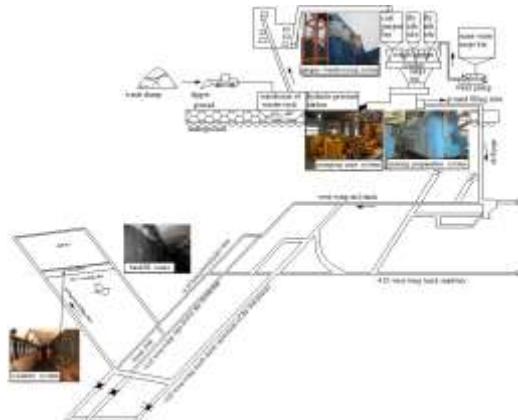


Fig.6. Whole system and the scene

F. The thin-slurry backfill technology

There are two types of slurry backfill technologies used in China according to the differences of backfill material, the slurry and slurry-like backfill technologies. The slurry backfill material is made of fly ash, water, cement, gypsum, lime, expansive agent etc. Fly ash and water are the main material with cement, gypsum, lime, expansive agent being the auxiliary materials. The solid concentration of slurry is 50% to 60% and it is delivered by gravity flow. The backfill body has the slight expansibility and can actively support the roof. The slurry-like is made of two types materials of A and B, with A being mainly made of bauxite mixed with retarding and dispersing agent, and B mainly made of gypsum mixed with compound accelerator agent. The A and B are mixed separately into A slurry and B slurry with water respectively in surface or underground. Then the A and B slurries are mixed in the certain distance to working face to fill the goaf. The water content of slurry-like is up to 97%, the whole backfill system includes slurry preparation system, pipe pumping or gravity self flow transportation system, slurry mixing system and working face backfill system. Since the backfill slurry has a strong liquidity, the working face needs to be mining up-dip. Taking Tianzhuang coal mine 1611 as an example where slurry-like backfill is used. The coal seam was at a depth of 228 m and had a thickness of about 0.8 m to 1.38 m with an average of 1.2 m. The panel has a width of 118 m and length of 420m. The long wall mining was carried out from down-dip to up-dip. The surface displacement monitoring showed the maximum subsidence was 34 mm. The slurry-like backfill field effects were shown in Fig. 7.



Fig.7. The slurry-like backfill scene

III. TECHNOLOGY CHARACTERISTICS, EVALUATION INDEXES AND APPLICATION CONDITION

A. The coal mine backfill mining technology characteristics and appropriate conditions

1)The roadway mining and gangue backfill technology

The key equipments are the gangue backfill machine and the belt transportation system; the main feature is its unique way of roadway excavation. Capital investment is low and roadway arrangement is flexible, backfill effect is easy to control. However the productivity is relatively low. This technology is suitable for coal seams with complex geological structures, subsidiary mining working face and mining under important buildings.

2)The conventional longwall mining and gangue backfill technology

The key equipments are the gangue backfilling machine and belt transportation system. The main feature is that it suits for long wall mining. The total capital investment is low and the productivity is high. However the backfill effect is difficult to control for the longwall working face. This technology is suitable for protecting the normal buildings of low significance.

3)The low pressure wind power pipe gangue backfill technology

The key equipments are roots blower system and belt transportation system, the main characteristic is the gangue tossed by roots blower, the whole systems investment is less and production is medium, and backfill effect is better as well as the longwall ordinary mining gangue backfill technology, it is appropriate to protect the ordinary buildings.

4)The fully-mechanized longwall mining and gangue compacting backfill technology

The key equipments are special backfill support, gangue transportation belt and hydraulic compaction device. The main feature is it is for the fully-mechanized longwall mining, the level of mechanization is high and coal productivity is high. The backfill effect is better than roadway mining gangue backfill, longwall mining gangue backfill and low pressure pneumatic pipe gangue backfill. However the total system investment is high. The technology is appropriate for uniform coal seam with simple geological structures, main mining panels and for protecting normal buildings.

5)The paste or paste-like backfill technology

The key equipments include gangue crushing and mixing system, pumping and pipeline delivery system and working face isolation system. The main characteristics are it is for the longwall mining, backfill strength and effect are high, and the productivity is high. However because the backfilling and mining operations are separated, when delivery pipeline is long, the pipe is easy to be blocked. It is appropriate for uniform coal seam, main mining panels and for protecting important buildings.

6)The slurry or slurry-like backfill technology

The key equipments are mixing and delivery system and working face isolation system. The significant

characteristic is that the usage of solid material is low and the amount of water can be up to 95% to 97% and underground outlet water can be recycled. It is appropriate for single coal seam, subsidiary mining working face and the protection of normal buildings.

B. The backfill mining indexes

The coal mine backfill mining indexes include capital investment, filling capacity, working face productivity,

filling cost, level of mechanization, system stability, convergence of roof and floor, subsidence factor etc. Subsidence factor, filling cost and productivity are the main indicators. The evaluation indexes for different backfill technologies are shown in Table 2, the strata movement characteristic of typical mines are shown in Table 3.

Table 2 Backfill technology evaluation indexes

Main indexes Backfill ways	Investment situation	Backfill Capacity (m ³ /h)	production Capacity (t/y)	Backfill cost (RMB/t)	Mechanized level	system stability	Deformation of fill body	Subsidence coefficient	Suitable conditions
Throwing gangue backfilling	small	30	200000	35	lower	general	large	0.4-0.5	Thin and medium thickness
Pneumatic pipeline gangue backfilling	small	35	300000	40	general	Relatively stable	general	0.2-0.3	Thin and medium thickness
Conventional throwing gangue backfilling	larger	50	400000	50	general	Relatively stable	general	0.3-0.4	medium thickness
Full-mechanical tamping gangue backfilling	larger	80	1000000	60	higher	stable	general	0.3-0.4	medium thickness
Paste-like backfilling	larger	100	500000	70	higher	stable	good	0.1-0.2	medium thickness
Paste backfilling	larger	120	600000	90	higher	stable	better	0.0-0.1	medium thickness
Slurry backfilling	small	50	300000	100	good	stable	good	0.2-0.3	Thin and medium thickness
Slurry-like backfilling	small	50	300000	120	good	stable	general	0.2-0.4	Thin and medium thickness

Table 3 Strata movement characteristic of typical mines

Mine	Backfill	Coal seam depth	Coal seam Thickness/m	q	b	tgβ	θ	S
zhangzhuang	Throwing gangue backfilling	270	1.4	0.22	0.32	1.7	80°	0.05H
Xiezhuang	Throwing gangue backfilling	130	2.7	0.14	0.36	1.6	70°	0.04H
Liangzhuang	Throwing gangue backfilling	128	1.9	0.13	0.4	1.15	73°	0.05H
Ezhuang	Throwing gangue backfilling	480	1.6	0.17	0.19	1.8	81°	0.05H
Shengquan	Pneumatic pipeline backfilling	350	1.2	0.13	0.26	1.8	82.5°	0.05H
Huaheng	Throwing gangue backfilling	650	1.4	0.08	0.15	1.3	81.5°	0.05H
Zhaizhen	Full-mechanized tamping backfilling	420	1.6	0.30	0.28	1.85	61.3°	0.036H
Panxi	Throwing gangue backfilling	350	6.74	0.15	0.32	1.4	86°	0.05H
Suncun	-5mm Paste-like backfilling	175	2.0	0.23	0.25	2.0	83°	0.04H
Caozhuang	-5mm Paste-like backfilling	570	2.0	0.24	0.26	1.8	75°	0.04H
Daizhuang	-25mm Paste backfilling	450	2.7	0.10	0.25	2.0	85°	0.05H
Bucun	Slurry-like backfilling	400	1.2	0.10	0.20	1.8	80°	0.03H
Tianzhuang	Slurry-like backfilling	200	1.2	0.3	0.28	1.5	75°	0.04H

IV. ISSUES OF BACKFILL MINING AND FUTURE DEVELOPMENT

A. The main issues of backfill mining

In recent decade, backfill mining technologies are well

developed in metal mines in China. However, the technology had not been widely used in coal mines. The main reasons are the difference in geology and mining conditions. Compared to metal mines mining, coal mine backfill mining consists of main several aspects. First, the

matching of mining and filling capacity is the most important. As is well known mining and backfilling operations cannot be parallel and will interfere each other. The operation cycle between mining and filling determines the productivity of coal mine, therefore the matching could be separated between mining and filling, backfill technology will have the large vitality and be used in coal mines. Balancing the production capacity of mining and filling is still an outstanding issue, the production capacity of mining and filling cannot match at present. Compared with the blast mining technology of metal mine, the full-mechanized mining has been realized in coal underground mining, that is to say cutting coal, loading coal, transporting coal, supporting and caving roof procedures have been mechanized. This has led many high capacity mines with the productivity of million to tens million tons in one working face. However filling capacity cannot match the mining technology at present. Secondly, the balance of supply and demand of filling material is also an important issue. The quantity of waste rock or tailing approximately accounts for 55% to 99% of ore production, moreover there are a great deal of other solid wastes, such as smelting slag etc. The balance of supply and demand of filling material has been realized. In coal mines however, the ratio of solid waste is low, and the quantity of coal gangue is only 15% of whole coal mining output, so it is very difficult to adopt the backfill mining for a wide area. How to find abundant and cheap backfill materials have become key consideration. Thirdly, the most important issue is the balance of backfill cost and mining benefit. The greatest advantage of backfill mining to other mining technologies is that the underground coal resources are maximized, and personnel safety is improved through the prevention of roof fall and goaf firing. However, backfill mining requires additional equipment and procedures, thus total cost will increase. The most important consideration is whether backfill economic benefit can offset backfill cost. Only when filling cost is less than cost of land destruction caused by mining and relocation of villages, the balance of backfill cost and mining benefit can be achieved. The backfill mining technologies could then be effectively applied. Lastly, due to the difference in geological and mining conditions, strata movement and failure characteristics are complex after coal seam is extracted, interference between filling and mining is unavoidable, and the parallel operations cannot be conducted in general.

B. The future development direction

Due to their high capacity of backfill mining and high degree of mechanization level, the fully-mechanized longwall mining and gangue compacting backfill technology, paste or paste-like backfill technology and slurry backfill technology are believed to have a great potential for future development and application. Owing to the goal to reduce gangue discharge, the primary gangue backfill technology and the low pressure pipe wind power gangue backfill technology should be

eliminated gradually. At present, the production capacity of solid fully-mechanized mining and gangue compacting backfill is less than 1 million tons per year, the production capacity of paste and slurry backfill is less than 500 thousands per year due to longer solidification time. The backfill cost of per ton is 8 to 20 USD. So future research should be focus on the parallel operation technology of filling and mining, isolation sealing technology of backfill space and cheap backfill materials.

V. CONCLUSION

The paper provides an review of present status of coal mining in China and main backfill technologies and their applications. Typical geology and mining conditions are introduced, the main system composition and technology characteristics are analyzed, and the advantages and disadvantages of different backfill technologies are evaluated. A backfill index is introduced which includes capital investment, backfill capacity, working face productivity, backfill cost, mechanized level, system stability, convergence of roof and floor, subsidence factor and so on. The surface movement parameters of typical mine areas are summarized. Finally, longwall fully-mechanized mining compacted gangue backfill technology, paste or paste-like backfill technology and slurry and slurry-like backfill technology are suggested as the future important technologies, whereas the primary gangue technology and low pressure pipe wind power gangue backfill technology should be eliminated gradually. Future research focus should be the parallel operation of filling and mining, isolation sealing technology of backfill space and cheap backfill materials.

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