Bulgarian Chemical Communications, Special Edition H, (pp. 101 – 106) 2017

Study and application of repeated mining with paste backfill to recover remaining strip pillars

Q.L. Chang, W.J. Tang, H.Q. Zhou *, J.B. Bai

Key Laboratory of Deep Coal Resource Mining, Ministry of Education of China; School of Mines; China University of Mining & Technology, Xuzhou, 221116, China

Received May 25, 2017; Revised July 20, 2017

In order to thoroughly recover coal resources under buildings, repeated mining with paste backfill to recover remaining strip pillars was proposed. Based on surrounding strata control theories, variation characteristics of surrounding strata structures after repeated mined with paste backfill was discussed. Also, the feasibility was analyzed. Through triangle structure of surrounding strata control, theoretical formula of remaining pillar width in repeated mining with paste backfill was studied. Relational expression of backfill material strength was ensured under conditions of paste backfill repeated mining with traditional limit analysis method. From the point of limited thickness mining, under paste backfill mining conditions, the controlling impact of paste backfill ratio on ground subsidence was analyzed and reasonable index was proposed. The roadway layout pattern and mining methods in mines were proposed. Also, parameters including paste backfill material strength, width of segregating coal pillars, backfill ratio were ascertained. According to field practice, after paste backfill reached full mining in the testing mine, the maximum subsidence of ground was 220 mm and the subsidence ratio was 0.076. The experiment results proved the rationality of this technology which had wide promotional value and practical significance.

Key words: Strip mining, Surrounding strata control, Remaining pillars, Paste backfill, Ground subsidence.

INTRODUCTION

China is a big country in coal producing and consuming. In 2011, the coal consumption accounts for 72.8% of the whole non-renewable energy consumption. Meantime, due to the dense population and wide distribution of buildings, vast coal resources exist under buildings. In order to protect constructions, those coal resources are always excavated by strip mining. But the excavation ratio of this method is less than 50%, a mass of permanent remaining resources were left [1,2]. With the rapid development of town constructions, more precious resources will be wasted seriously. What's more, joint fissures in coal pillars are developed. In this case, coal pillars are easily pressed softly, even broken to pieces. This damaging range will extend to internal pillars gradually, which will cause the un-stability of coal pillars suddenly and be a threat to safe mining [3-5]. Therefore, realization of repeated mining of strip coal pillars has extreme significance not only in safe mining but also in improving the excavation ratios of coal resources.

Gangues are associated waste during mine production process. In the same time, at present, they are one of major emission solid wastes in China. Fly ash is the maximum discharge powder waste produced by powder plants. The treatment of those two kinds of wastes in underground has arisen people's attention and application has been conducted in some coal mines [6-8]. Therefore, ground subsidence control, improving mining ratio of coal resources and underground treatment of wastes including gauges, fly ash are combined together. Furthermore, new repeated mining with gauge solid waste as aggregates to recover strip coal pillars was proposed.

Project profile: Ground villages in the range of Dai village Coal Mine which belongs to Zibo Coal Mine Company with Limited Liability in Shandong Province are pretty dense. There are 78 natural villages, 13 thousands households and 50 thousand people in total. Coal resources under villages accounts for 73.6% of the mine total storage. In order to realize the safe mining of coal resources under buildings, strip mining to excavate coal resources under buildings was always adopted in Dai Village Coal Mine and succeeds. But with the extending of mining range, remaining coal pillars increased gradually. According to statistics, up to the end of 2011, the coal pillars under buildings accounted for 94.6% of the total storage. The recoverable reserves of this mine declined to 21.044 million ton and the mine service lift could only maintain to 7.5a. In order to protect ground constructions, repeated mining with paste backfill to recover remaining coal pillars was adopted, which is beneficial to improve mining ratio of resources and expand service life of coal mines.

230 panel was the first mining area in this mine.

* To whom all correspondence should be sent:
E-mail: zkdcql@163.com

Strip mining was used in this whole area and the excavation ratio was merely 37%. Remaining pillar resources rose up to more than 9 million ton. The mining depth in this area was 470 m. 3_{up} coal seam was mined and this seam was stable. The minimum thickness is 2.5 m and the maximum thickness is 3.2 m. The average thickness is 2.9 m. The dip angle ranges from 3 to 12 degrees, with an average angle of 6 degrees. The density of this coal seam is 1.35 t/m^3. The roof is medium stable.

EXPERIMENTAL

Repeated mining with paste backfill to recover strip pillars

Technology procedures

The technology procedures were stated as follows. Firstly, mining roadways were excavated in segment coal pillars. After the strip was mined, roadways were tunnelled in narrow pillars remained in coal pillars surrounding the gob area (Fig.1 (a)). Secondly, paste backfill mining was adopted to recover remaining pillars. After the producing system of working face was formed, with the advancement of the working face, paste isolation strip was constructed in the back in order to form backfilling space after certain steps. During the backfill process, roadways and gobs were fully backfilled. The backfill strip could provide support to the overlying strata, preventing them from failure. In this way, the purpose of controlling ground subsidence and protecting buildings is achieved. Furthermore, safe mining of coal pillars is realized (Fig. 1 (b)).

Structural characteristics of surrounding strata

(1) Basic features of strata behaviours in the mining stope

Under general conditions, with the conduct of coal mining, combined movement in the form of panel will occur in roof upon the working face. It is always controlled by rigid strata which have better mechanics in the roof. From down to up, the area declines. Therefore, “Big structure” forms at a depth in main roof. The upper load on this stable structure is transferred to two sides of the mining stope through bearing points on coal and rock rather than applied directly to the stope [9].

(2) Stability of critical blocks

When strip working face is conducting, with the advancement of the working face, immediate roof close to remaining pillars will collapse. But the main roof will rupture at the depth of coal seam. The bearing point will always situate in remaining coal pillars. Therefore, arc triangle panel (the critical block) will occur. Based on key strata theory of overlying strata in the stope, mechanical model of paste backfill to rover remaining pillars was established, which is shown in Fig. 2.

After the key strata collapse, the key block of B subsides and rotates. Then it contacts with gauges in the stope. For certain deformations, it will be subjected to support from broken gauges and pillars. In the same time, it will suffer griping impact from the key block of C and key block B. Furthermore, it will also receive horizontal force effect from surrounding blocks shown in Fig.2. Therefore, this key block of B is in the “small structure”. The stress state is relatively balanced and the stability is good. Furthermore, it obeys to the stability theory of S-R (sliding-rotation). As this structure is affected by repeated mining, the suffered load increases continuously. The stress status between blocks will change. However, as long as the technological parameters of paste backfill are reasonable, the dynamic balance can still remain. Also, the main roof on the working face will not rupture [10, 11].

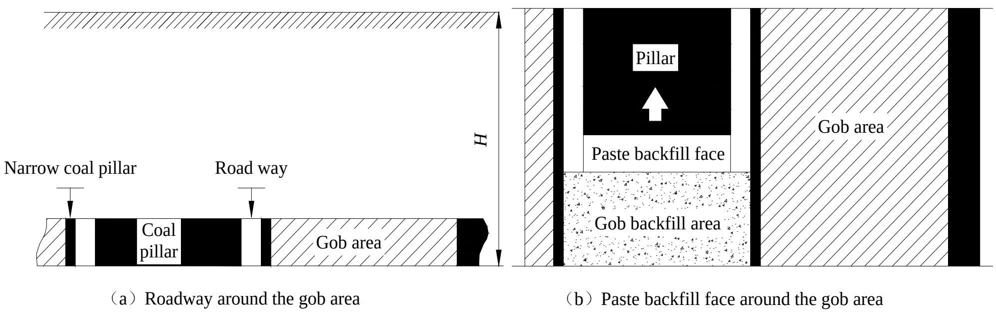

Fig. 1. Diagram of paste backfill mining to recover remaining pillars. (a) Layout diagram of gob-side entry driving; (b) Schematic plot of paste backfill mining.

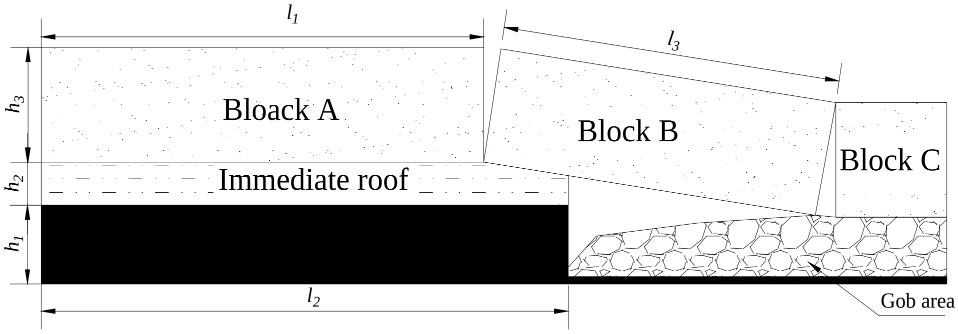

Fig. 2. Schematic diagram for mechanical structure of paste backfill to recover remaining pillars

(3) Stability analysis of surrounding strata with paste backfill to recover remaining pillars

After the working face is conducted, the "big structure" in the main roof will bear partial surrounding strata weight in the stope. The bearing point is located upon remaining coal pillars on two sides in the stope. "Small structure" mainly bears the collapsed rock weight under "big structure". Under general conditions, the strength of backfill body is large (around 5 MPa). The paste backfill step only ranges from 2 to 4 m. The process of paste backfill mining is actually equivalent to a moving open-off cut, which has relatively small impact on "the big structure" as well as "the small structure" in the stope and has no effect on the stability of the whole structure [12-14]. Therefore, it is theoretically feasible to conduct paste backfill mining technology to recover remaining pillars.

After paste backfill is conducted, the paste body can backfill the gob in time and congeal rapidly to supporting body with certain strength. In the same time, the backfill body has the strain strengthening characteristics, which is beneficial to prevent main roof from subsiding excessively and control movement as well as deformation of overlying strata. This can effectively ensure the stability of paste backfill body and surrounding rock including the main roof in the stope, achieving the purpose of controlling ground subsidence and protecting the safety of surface buildings.

Key of repeated mining with paste backfill to recover remaining pillars

According to Fig.1, the key technology is the stable and reasonable strength of paste backfill body and backfill ratio. The stability of surrounding rock becomes bad when the mining roadways of the working face get more close to peak value of lateral abutment pressure. Furthermore, the waste of resources becomes larger. The smaller the pillar width is, the worse the stability is. And this is not beneficial to construct roadways and roadway support. That the strength of paste backfill body gets larger is more beneficial to control the main roof and keep it stable. But this will give rise to more paste backfill cost and waste of material strength, which has a relatively worse economic benefit. However, if the paste backfill body has a smaller strength, it will cause the movement and deformation of overlying strata, which is not beneficial to control surface subsidence and protection of surface buildings. What's more, the purport of paste backfill may lose. Reasonable backfill ratio will reduce the consuming of backfilling materials, lessening backfill cost, which has an optimal combination between usage of backfill materials and surface subsidence control.

Determination of pillar width

After the strip working face is mined, the arc triangle block will occur within the main roof in the stope, which produces stress declining area, stress improving area and original stress area in remaining coal pillars. In order to minimize the impact of surrounding strata stress, roadways should be arranged in the stress declining area near coal pillars, which is most beneficial to control surrounding strata and keep pillars stable. In order to improve profits of mines and excavation ratio of coal resources, narrow fringe coal pillars should be remained to most extent. However, if coal pillars are too narrow, they will deform and damage rapidly and easily, which determine the decline of anchoring force of supporting structures and reduce the supporting strength of surrounding strata. In the same time, cluster winds may easily happen, which has potential safety accidents.

Reasonable coal pillar width B can be calculated as $B= B_1+B_2+B_3$ according to Fig.3. To be more specific, B_1 is pillar width in plastic area, while B_2 is stability coefficient of coal pillars and generally calculated as (B_1+B_3) ×40 %. As for B_3, it is the length of rock bolts and picked as 1.6 m.

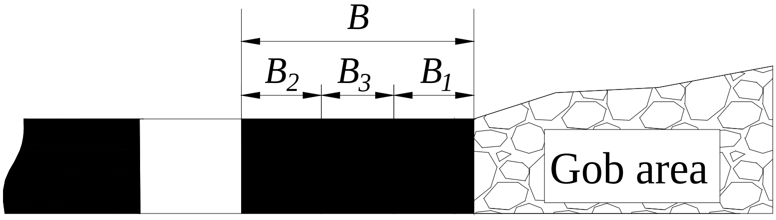

Fig. 3. Schematic diagram of calculating pillar width

The value of B_1 is calculated as the following formula.

$$B_1=\frac{mA}{2\tan\varphi_0}\ln\left(\frac{K\gamma H+\frac{C_0}{\tan\varphi_0}}{\frac{C_0}{\tan\varphi_0}+\frac{P_z}{A}}\right)$$

Where, m is coal seam thickness, 2.9 m; A is coefficient of lateral pressure, $A=V/(1-V)$, and $v=0.22$; φ_0 is the internal frictional angle and calculated as 27. C_0 is cohesive force, 2.3 MPa; K is the stress concentration coefficient, 2.2; γ is unit weight of rock mass, 25 kN/m^3; H is the mining depth, 470 m; P_Z is the resistance of supports, 0.

According to mining conditions of practical mines, it can be calculated that B_1=1.69 and B_2=1.0~1.7m. Therefore, it can be obtained that B=4.3~5.0 m. In order to keep the anchoring effect of rock bolts, the ultimate reasonable width of coal pillars is 5.0 m.

Determination of paste backfill body

After paste backfill is conducted, the paste backfill body situates the unidirectional stress status. Theoretically, the tolerate strength of paste backfill body under unidirectional stress status can be calculated in the following four formulas: Obert-Kwvall/Wang expression (suitable for pillars whose aspect ratio ranging from 1 to 8), Holland expression (suitable for pillars whose aspect ratio ranging from 2 to 8), expression of Salamon-Mnuro and Bieniawski formula. Due to the fact that the field working face is 96 m and mining height is 2.9 m, therefore, the aspect ratio is 33. It is apparent that only the latter two formulas can be selected to calculate the tolerate strength of backfilling body.

Generally speaking, the joints and fractures in coal seams develop and the whole integrity is bad. The deformation destruction has typical plastic and brittleness material features. The fine plastic features of paste backfill body are beneficial to keep backfilling body stable, which has been confirmed in practice. In sum, after paste is backfilled in Dai Village Coal Mine, the later strength of paste backfill body should be calculated according to Bieniawski expression, which is more reasonable and safer.

It can be known from Bieniawski expression that after remaining coal pillars are mined, the tolerate strength [σ] of paste backfill body can be calculated as:

$$\sigma_c=\frac{k*\gamma H\left(1+We/Wp\right)}{\sqrt{D/0.9}*(0.64+0.36*w/h)^{1.4}}$$

Where, k is the safety coefficient;γ is the unit weight of rock strata,25 kN/m^3; H is the mining depth, 470 m; D is the diameter of the specimen, mm; We is the width of mining strip, m; Wp is the width of coal pillars, m; W is the width of paste backfill working face, m; h is the mining height, m.

Based on the calculating formula, safety coefficient was 1.5-2.0. According to practical mining conditions of mines, single axial compressive strength of paste backfill body could be determined. Under the standard conditions in the laboratory, when the width of mining coal pillars is less than 50 m, the compressive strength of paste body after 28d should not be less than 5.0 MPa; while when the width of mining coal pillars is less than 100 m, the compressive strength of paste body after 28d should not be less than 2.6 MPa.

Determination of backfill ratio

The research analysis shows that the major factors that affect the surface subsidence induced by backfill mining includes compressive ratio of the paste body, the roof subsidence value before backfill and yawning contacting value. In order to analyse simply, all these parameters were uniformly transferred into backfilling ratio (the specific value of backfill material volume versus volume of gob). As key parameters that reflect backfill effect, the value of backfill ratio is directly related to the degree of surface subsidence control. Under same conditions, the larger the backfill ratio is, the bigger the space where backfill materials occupy in the gob is. And the movement space of strata becomes smaller. In addition to that, the controlling effect of surface subsidence is better. On the contrary, the surface subsidence controlling effect becomes bad.

However, in the same time, the consuming of backfill materials becomes large if the backfill ratio is high. And the amount of backfill work becomes large. Also, the cost of backfill goes high. However, if the backfill ratio is too small, the ground subsidence controlling effect cannot be guaranteed. Therefore, it is really important to select an appropriate backfill ratio. On the basis of limited thickness mining, the backfill ratio of calculating formula can be obtained [15]:

$$\eta \geq 1 - \frac{[\varepsilon]H}{1.52mbq\tan\beta\cos\alpha}$$

Where, η is the backfill ratio; m is the coal seam thickness, 2.9 m; H is the depth of coal seam, 470 m; $[\varepsilon]$ is the maximal tolerate horizontal deformation value of surface constructions, 2 mm/m; b is the horizontal movement ratio, 0.29; q is the subsidence ratio, 0.91; β is tangent of major affecting angle, 2.71; α is the dip angle of coal seam,6 degree.

Therefore, the backfill ratio can be calculated as:

$$\eta \geq 1 - \frac{2\times 470}{1.52\times 2.9\times 1000\times 0.29\times 0.91\times 2.71\times \cos 6} = 0.7$$

RESULTS AND DISCUSSION

1 Roadway layout and mining techniques

The roadway layout scheme of the working face was shown as follows: The position and size of backfill working face: it was arranged in the middle of strip pillars and the length of the working face was 95 m. The position and size of roadways that belong to backfill working face: There were two roadways which were the orbit roadway and haulage roadway. To be more specific, the roadway width was 4.0 m (the roadway height equaled to coal seam thickness) and supported by bolt-mesh-anchor. Considering the impact that the gob has on both two sides of coal pillars, the width of coal pillar that was used to protect roadways should be selected as 5.0 m, which is shown in Fig.4.

The fully mechanized paste backfill mining technique was adopted. And the backfill step ranged from 2 to 4 m. On the basis of fully mechanized process, coal cutting, support movement and scraper conveyer motivation was operated. When the backfill step was reached, the paste backfill was conducted.

Analysis of application effect

Those four adjacent coal pillars have been repeated mined with backfill in Dai Village Coal Mine. From the deformation status of roadway surrounding strata, only slight fissures occurred on the top of one coal pillar. The other remaining strata surrounding roadways were controlled well, which completely satisfied the normal safety requirements.

Measurements of mine pressure indicated that no strata behaviour occurred in backfill working faces. The average compressive strength of backfill body was 3.2 MPa, satisfying the strength requirement. The pressure that backfill body in the gob tolerated was about 12 MPa, basically reaching original rock stress. In the same time, the measurements showed that after full mining, the surface maximum subsidence was 220 mm and the subsidence ratio was 0.076, ensuring the safety of surface buildings. The field practices certified that the repeated mining with backfill to recover coal pillars succeeded.

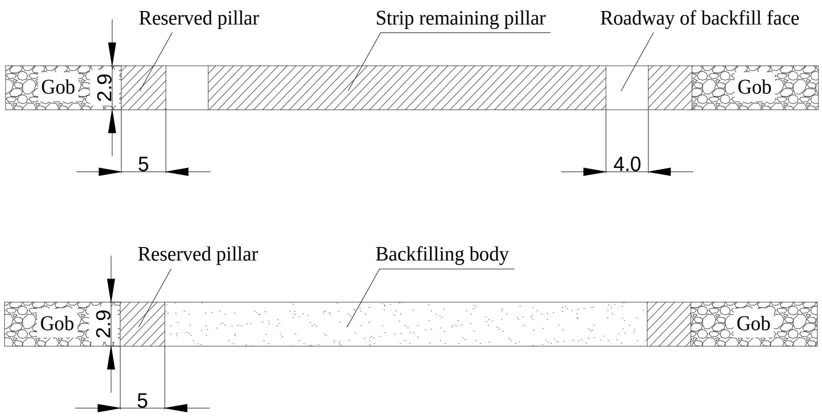

Fig. 4. Schematic diagram of paste backfill mining to recover remaining pillars

CONCLUSION

1) In order to repeated recover remaining coal pillars produced by strip mining and improve the

excavation ratio of coal resources, new paste backfill technology to replace remaining coal pillars produced by strip mining with aggregates of gangues was proposed in this paper. The field practice showed that this technology was feasible completely, which provided reliable new technology for recovering remaining coal pillars under surface buildings generated by strip mining.

2) In order to analyze the stability characteristics of remaining coal pillars by strip mining, the main technology process and procedures during paste backfill mining to recover remaining coal pillars were stated. Furthermore, the mechanical analyzing structural model was discussed. Also, parameters including the coal pillar width, backfill body strength and backfill ratio during paste backfill mining in practice mines were analyzed and determined.

3) The field practice results indicated that after remaining coal pillars produced by strip mining was recovered in this technology, no strata behavior occurred in the backfill working face. When full mining was reached, the maximum surface subsidence was 220 mm and the subsidence ratio was 0.076. The damaging level of surface buildings was in the range of Level I, indicating that no repair was need.

The repeated mining technology with gauge-paste backfill to recover strip coal pillars can not only achieve safe mining of permanent remaining coal pillars but also provides reliable new technology for mining under buildings. In the same time, solid wastes including gauges and fly ash are fully utilized, which promotes the resource utilization of industry wastes and has marked economic and social benefic. In sum, this technology has wide popularization and application values.

Acknowledgements: *The present research work was supported by the National key basic research development program sub-project （973 Program: 2015CB251600）; A Project Funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions（PAPD）; the Fundamental Research Funds for the Central Universities (NO. 2014XT01); the National Natural Science Foundation of China (No.51574227).*

REFERENCES

1. M.G. Qian, X.X. Miao, J.L. Xu, China University of Mining and Technology Press, Xuzhou, 2003.
2. H.Q.Zhou, C.J. Hou, X.Q. Sun, Q.D. Qu, D.J. Chen, *J CHINA U MIN TECHNO*, **33**(2), 155 (2004).
3. J.B. Bai, China University of Mining and Technology Press, Xuzhou, 2006.
4. Y.G. Chen, S.L. Lu, China University of Mining and Technology Press, Xuzhou, 1994.
5. X.H. Li, Q.L. Yao, N. Zhang, D.Y. Wang, X.G. Zheng, X.L. Ding, *J CHINA COAL SOC*, **25**(4), 420 (2008).
6. Q.L. Chang, H.Q. Zhou, J.B. Bai, *J MIN SAF ENG*, **28**(2), 279 (2011).
7. D.S. Zhang, H.S. Wang, L.Q. Ma, *J CHINA COAL SOC*, **35**(10), 1549 (2010).
8. H.Q. Zhou, C.J. Hou, X.Q. Sun, Q.D. Qu, D.J. Chen, J *CHINA U MIN TECHNO*, **33**(2), 155 (2004).
9. X.H. Li, N. Zhang, C.J. Hou, *J CHINA U MIN TECHNO*, **29**(2), 186 (2000).
10. C.J. Hou, X.H. Li, *J CHINA COAL SOC*, **26**(1), 1 (2001).
11. M.G. Qian, X.X. Miao, F.L. He, *J CHINA COAL SOC*, **19**(6), 557 (1994).
12. L.Q. Ma, D.Zhang, H. Wang, Y.S. Li, *CHIN J ROCK MECH ENG*, **29**(4), 674 (2010).
13. M.G. Qian, X.X. Miao, J.L. Xu, *J CHINA COAL SOC*, **32**(1), 1 (2007).
14. J.X. Zhang, X.X. Miao, *J CHINA U MIN TECHNO*, **35**(2), 197 (2006).
15. J.P. Du, L.Q. Wang, China University of Mining and Technology Press, Xuzhou, 2003.
16.