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An integrated treatment technology for ground fissures of shallow coal seam mining in the mountainous area of southwestern China: a typical case study

Introduction

With the implementation of China's western development strategy, the economy of the western provinces has achieved significant growth. Consequently, the western coal mining area has become the focus of China, with the coal resource output increasing annually (Zhou and Chen 2014). Many shallow coal seams with a buried depth less than 200 meters occurred in the western area, accounting for more than 30% of the total explored coal reserves (Ning 2017). The shallow buried coal seam mining area in China can be divided into two sections, the northwestern section and the southwestern section (Liu et al. 2012; Zhu et al. 2014). Regarding the southwestern section, due to its special geographical location and complex topography, the landform is mainly mountainous with steep topography. Currently, many small and medium-sized coal mines are located in this area, accounting for nearly 80% of the total. Being restricted by a low economic development level, most of the coal gangues, as a type of resource, are wasted. Untreated coal gangue has generated serious problems for the society, the environment and the economy (Bian et al. 2010). For example, untreated coal gangue occupies much land, and accordingly, the proportion of cultivated land and forest land has decreased. SO_2 and NO_x generated from coal gangue combustion pollute the soil and underground water (Fabia et al. 2013; Yang et al. 2016; Tan et al. 2017). In addition,

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the ground sinkhole induced by coal mining requires particular attention. Due to the shallow buried depth of the coal seam, many ground fissures are generated on the surface. Indirectly, this can cause water and soil loss, vegetation deterioration, landslides and other hazards (Bell and Genske 2001; Huang et al. 2015; Rahmanpour 2013). In particular, when ground fissures connect with the gob, it will directly affect the safety of the coal mine.

Over the past decade, comprehensive utilization of coal gangue has mainly involved electricity generation, production of building materials, road-building and coal mine gob backfilling (Guo et al. 2014). Coal gangue backfilled mining technology is being increasingly used in China to recover coal resources beneath buildings, railways and water bodies (Dai et al. 2014; Zhang et al. 2014). Since ground fissures are caused by underground mining activities, their treatment should take mining activities into account. Previous studies were mainly focused on the development characteristics of ground fissures, with few studies conducted on the treatment of ground fissures. Sandy soil filling technology (SSF) has been used to treat ground fissures for many years. However, because of the great depth and irregular occurrence of a ground fissure, the treatment effect of SSF is poor (Li et al. 2017; Mohseni et al. 2017). As a ground fissure is caused by underground mining activities, its treatment should take mining activities into account. An integrated treatment technology is proposed to treat ground fissures. More specifically, coal mines adopt the strip mining method and then use the reserved coal pillar as a separated wall during the coal gangue material backfilling process, and the crushed coal gangue is used to fill the ground fissure. Therefore, rationally applying this technology in the southwestern coal mining area will be effective for both ground fissure treatment and environmental protection.

Taking Anshun coal mine in Guizhou Province of China as a typical case study, this paper describes the application of integrated treatment technology in shallow buried coal seam mining in southwestern China. The mixture of coal gangue, fly ash and ordinary Portland cement was experimentally studied via uniaxial compressive tests in the laboratory to determine its compression strength. Moreover, the FLAC^{3D} numerical simulation software was used to determine a reasonable mining scheme. Engineering practice results indicate that integrated treatment technology could effectively control surface sinkhole and ground fissures development. This paper presents a novel approach of combining ground fissure treatment technology and environmental protection in southwestern China.

1. Case study

1.1. Mining and geological overview of Anshun coal mine

The Anshun coal mine, located in Anshun city, Guizhou Province, China (Fig. 1), covers a mining area of 22 km^2. The coal bearing strata belong to the Longtan Formation, upper Permian. The main minable coal seam is M9 coal, with an average thickness of 1.65 m.

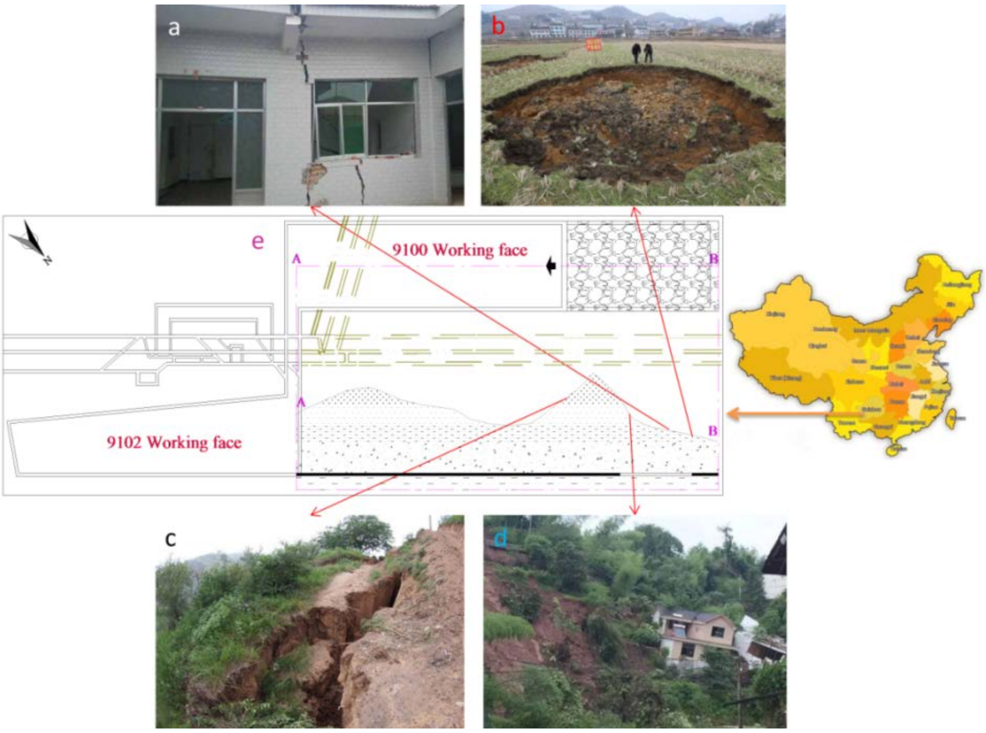


Fig. 1. Environmental hazards caused by mining activities in the Anshun coal mine
a) fissures in buildings, b) surface sinkhole, c) ground fissures, d) landslide,
e) 9100 working face deployment

Rys. 1. Zagrożenia środowiskowe spowodowane działalnością górniczą w kopalni węgla kamiennego Anshun
a) pęknięcia w budynkach, b) deformacje powierzchniowe, c) pęknięcia gruntu, d) osuwiska,
e) rozmieszczenie 9100 przodków roboczych

This study involves a typical area: the 9100 working area with a striking length of 896 m and an inclination length of 175 m. According to the field geological survey, the ground surface of this working area is mainly mountains, the maximal and minimal buried depths are 217.5 m and 106.3 m, respectively, and the maximal altitude difference is nearly 128 m. The 9100 working area adopts the long wall mining method, a typical shallow buried coal seam mining approach. In the process of coal recovery, the ground surface exhibited many ground fissures; moreover, several landslide hazards occurred. At present, the 9100 working face is being mined. To solve surface sinkhole and ground fissure development, integrated treatment technology was used in the later stage.

1.2. Geological investigation of ground fissures

The ground surface of the 9100 working face is mainly the mountainous area, with the maximum slope gradient of 54.7° and the average slope gradient of 26.6°. Ground fissures are caused by underlying strata movement and slope sliding, resulting in the cracking of the surface soil layers. The development regularity of ground fissures is affected by the buried depth of coal, the mining thickness, the lithology of the overlying strata and topography conditions, such as the slope gradient and the surface soil layer (Liu et al. 2016). To determine the characteristics of ground fissures in the Anshun coal mine, the geological survey was conducted by using the X91 (Global positioning system) GPS – (Real-time kinematic) RTK receiver and the steel ruler. One monitoring line was placed every 100 meters, and eight monitoring lines were arranged along the striking length of the 9100 working face, as shown in Fig. 2. The X91 GPS-RTK receiver is used to monitor the positions of the ground fissures, and the width and the fall are tested using the steel ruler. The geological survey results of the ground fissures were collected by field investigations, as shown in Table 1. According to the results, the maximum width of ground fissures is 1.05 m, whereas the minimum width is 0.08 m. Moreover, the maximum fall of the ground fissures is 1.42 m, whereas the minimum fall is 0.12 m.

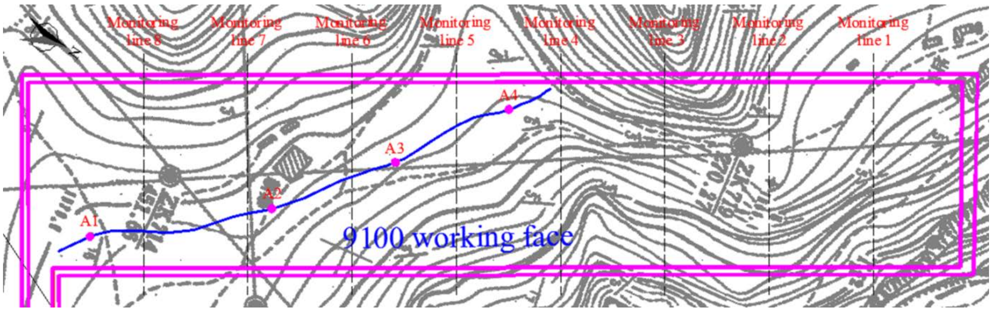


Fig. 2. Monitoring lines for ground fissures

Rys. 2. Monitorowanie pęknięć gruntu

1.3. Experiments of the rock mechanical properties

To better understand the rock mechanical properties, laboratory tests were conducted on the rock samples collected from the roof of the haulage roadway. The experiments were conducted with a servo-controlled testing system (MTS815.03) with a maximum axial load of 4600 kN and a maximum confining pressure of 140 MPa. The uniaxial tensile strength was determined by conducting the uniaxial tensile tests on a total of 10 rock cores, and the uniaxial compression strength, elastic modulus and Poisson's ratio were determined by implementing the uniaxial compression tests on a total of 20 rock cores (Fig. 3). The average

Table 1. Field investigation results of ground fissures

Tabela 1. Wyniki badań terenowych pęknięć gruntu

Monitoring line	Width [m]	Fall [m]	Fissure angle [°]	Slope gradient [°]
1	0.15	0.23	58.7	12.5
	0.27	0.42	61.2	20.9
2	0.67	0.89	75.4	49.5
	0.73	1.15	82.1	54.7
3	1.05	1.42	73.2	43.4
	0.90	1.21	78.3	39.7
	0.84	0.97	69	46.2
4	0.17	0.18	47.3	12.3
	0.14	0.22	52	33.3
5	0.15	0.16	64	26.1
	0.08	0.12	56	6
6	0.22	0.56	56.8	12.3
	0.34	0.78	61	14
7	0.57	0.63	59	17.6
	0.43	0.72	72.2	25.4
8	0.66	0.75	70.5	24.8
	0.78	1.00	67	31.5

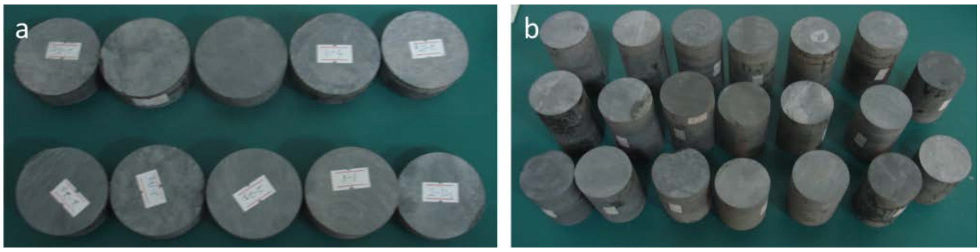


Fig. 3. Rock samples used in the experiments
a) rock cores for the tensile tests, b) rock cores for the compression tests

Rys. 3. Próbki skał użyte w doświadczeniach
a) rdzenie skalne do prób rozciągania, b) rdzenie skalne do prób ściskania

values of the mechanical parameters determined from the experimental results are shown in Table 2.

Table 2. Rock mechanical property experimental results

Tabela 2. Wyniki eksperymentalne właściwości mechanicznych skał

Lithology	E_i [GPa]	σ_c [MPa]	σ_t [MPa]	v
Coal seam	3.46	19.73	0.90	0.31
Silt clay stone	10.97	76.65	2.49	0.21
Limestone	12.42	115.8	2.20	0.18
Siltstone	9.86	89.7	2.75	0.23
Sandstone	11.05	83.42	3.60	0.22

2. Integrated treatment technology

2.1. Technical principle

Integrated treatment technology includes underground backfilled technology and ground fissure treatment technology. It fully considers the surface sinkhole caused by underground mining activity. Moreover, coal gangue produced by roadway driving is also fully used.

Integrated treatment technology adopts the strip mining method in the underground working face. The technical principle of the underground backfilled technology can be described as follows (see Fig. 4): first, the width of the coal mining body and the reserved coal pillar is determined rationally based on theoretical analysis in the process of coal recovery; next, the reserved coal pillar is used as a separated wall when filling material is backfilled for the purpose of achieving a better backfilling effect (this backfilling method was named the partitioned backfilling method); finally, the gob is used to place the backfilling equipment to implement the backfilling process.

In addition, the process of the ground fissure treatment technology is divided into three steps (see Fig. 5): the width, depth and angle of ground fissures are first determined by field geological surveys; next, the filling material is backfilled into the ground fissure, and the loess, with a thickness of more than 1.0 meter, is backfilled; finally, the backfilled material is solidified, and then, vegetation is planted at the surface to protect the environment.

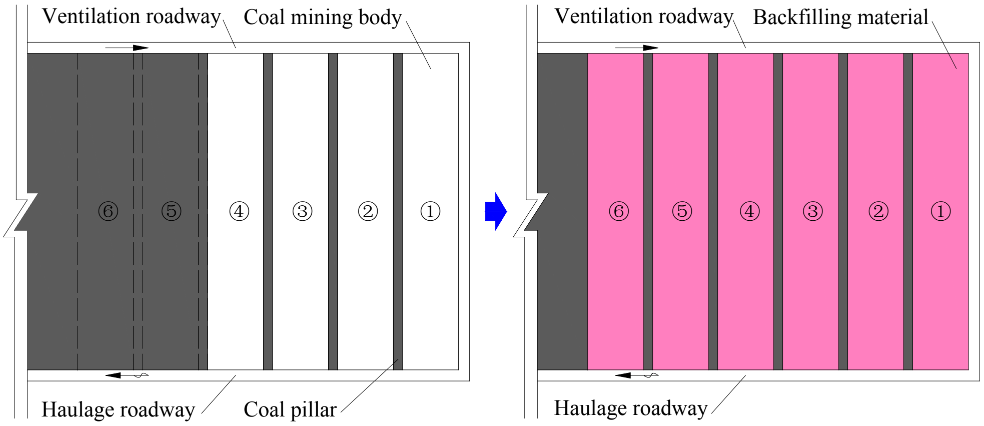


Fig. 4. Procedure of underground backfilled technology

Rys. 4. Procedura technologii podsadzki

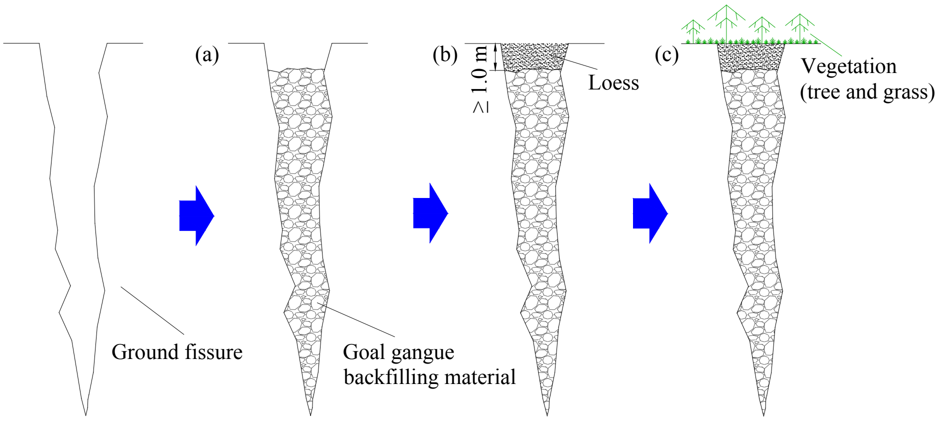


Fig. 5. Three-step method of ground fissure treatment technology
a) filling material backfilled, b) loess backfilled, and c) vegetation planting

Rys. 5. Trójstopniowa metoda technologii zabiegów pęknięć gruntu
a) wypełnienie materiałem podsadzkowym, b) wypełnienie lessem, c) sadzenie roślinności

2.2. Technical process

The system of underground backfilled technology is composed of the backfilled material conveying and storage system, the backfilled material mixing system, the water supplying system, the detection system and the pipeline system.

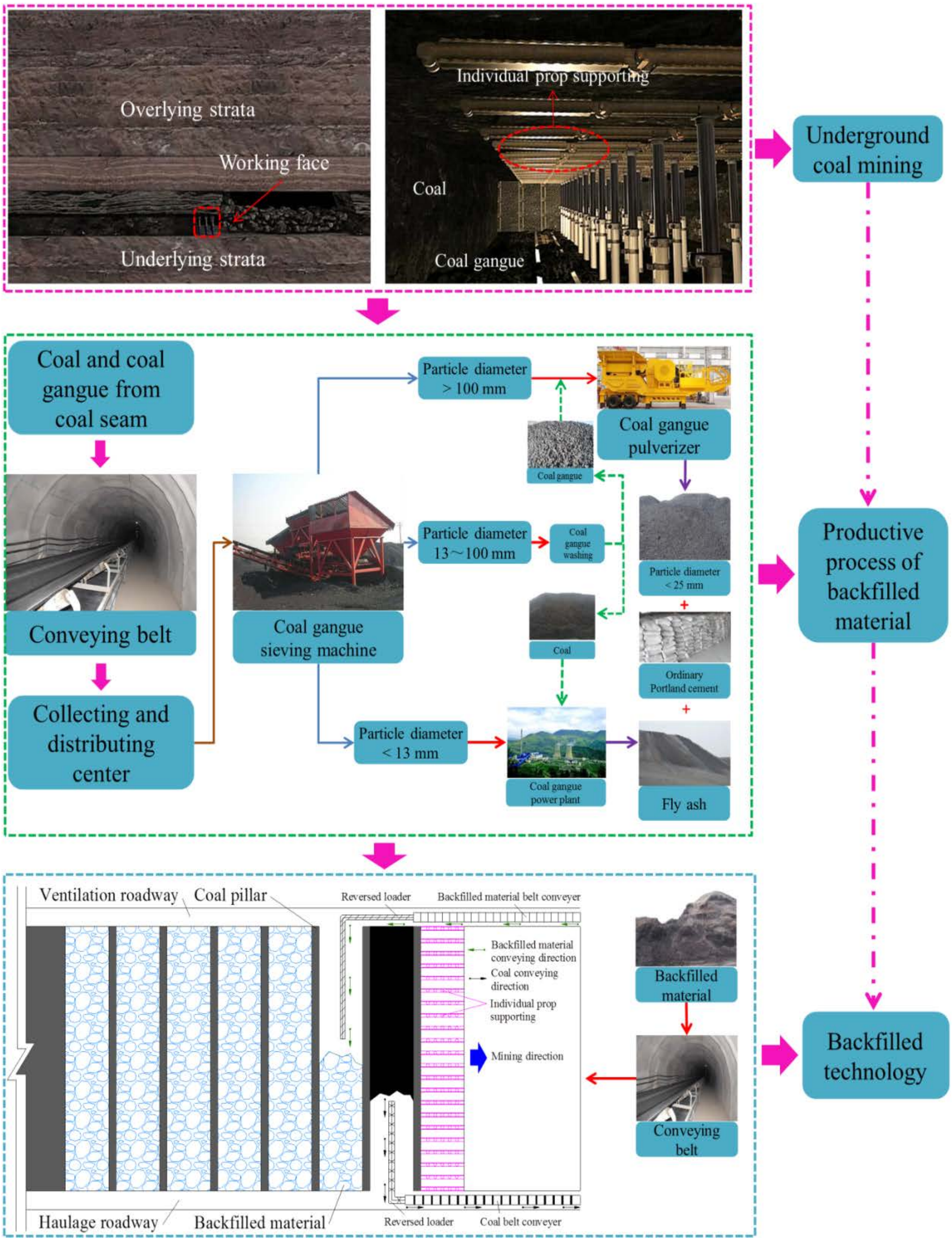


Fig. 6. Technical process of the underground backfilling approach

Rys. 6. Proces techniczny podsadzki

After being crushed, coal gangue is stored in a yard specially designed for storing coal gangue. Next, crushed coal gangue is supplied into the mixing tank by using a conveying belt. The ordinary Portland cement and fly ash are conveyed by a tanker and then discharged into the storage yard. After mixing the crushed coal gangue, ordinary Portland cement and fly ash, the mixture was conveyed to the gob. The process of conveying backfilled material can be described as follows (see Fig. 6): backfilled material storage → conveying system → underground conveying pipeline → haulage roadway → backfilled material conveying roadway → backfilling of the gob.

3. Experimental tests of the backfilled material

3.1. Material and methods

Experimental tests of backfilled materials were also conducted by using the servo-controlled testing system (MTS815.03), as shown in Fig. 7. All test samples were prepared by crushing and sieving into a cylinder with the following dimensions: diameter × height: 55.4 × 78.5 mm, following the suggested experimental test method of rock mechanics. Coal gangues with a selected diameter of 0-25 mm were mainly collected in the process of coal mining and roadway driving in the Anshun coal mine, fly ash was mainly collected from a nearby power station, and ordinary Portland cement with a strength class of 42.5 was used. According to the chemical composition experimental result of the fly ash, the average proportion of SiO_2, Al_2O_3, Fe_2O_3 and CaO is 45.407%, 25.65%, 13.602% and 3.043% respectively. The kind of fly ash belongs to the low-calcareous and F class according to the classification standard. Coal gangue, fly ash and ordinary Portland cement were mixed by an agitator, and then, the mixed material was placed into a mold with a size of 100 × 100 × × 100 mm. Samples were made with different ratios of coal gangue:fly ash:ordinary Portland cement of 1:0.1:0.16, 1:0.3:0.18 and 1:0.5:0.22. After the experimental samples were made,

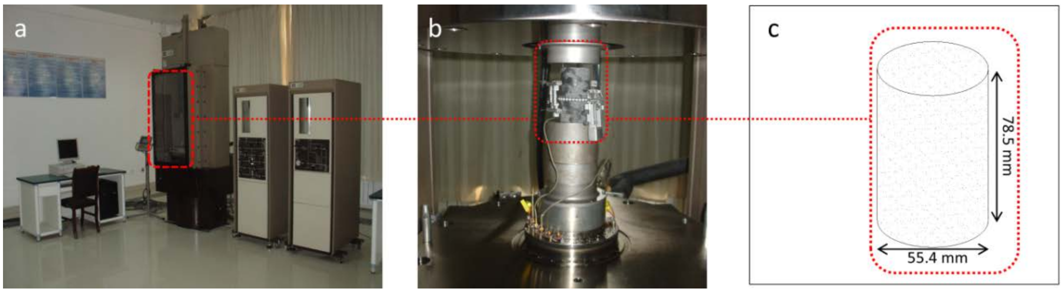


Fig. 7. a) Servo-controlled testing system, b) sensors for the experiment, c) cylindrical samples

Rys. 7. a) Sterowany układ badawczy, b) czujniki do eksperymentu, c) próbki cylindryczne these samples were placed into a curing room with a temperature of (20±2°C) and a moisture level of approximately 40%. The compressive strengths of the samples with three different ratios of 1:0.1:0.16, 1:0.3:0.18 and 1:0.5:0.22 were determined under the same curing age, while the compressive strengths of the samples with different curing ages of 3 d, 7 d, 14 d and 28 d for a given ratio were also determined, following the Chinese Standard Method GB/T 50081-2002.

3.2. Experimental result analysis

According to the results of the compression test, as the curing age increases, the compressive strengths of the samples also increase (Fig. 8). The compressive strength values range from 1.04 MPa to 4.01 MPa, reaching a maximum value when the curing age is 28 d. When the mixed ratio of coal gangue:fly ash:ordinary Portland cement is 1:0.3:0.18, the compressive strength varies from 1.23 MPa to 4.01 MPa, indicating that this ratio has the maximal compressive strength. Therefore, this ratio of the backfilled material is determined in this study.

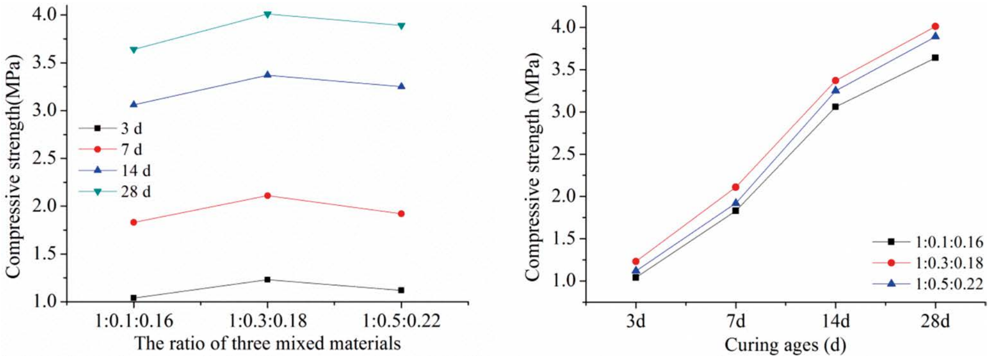


Fig. 8. Compression strength of backfilled materials

Rys. 8. Ściśliwość materiału podsadzkowego

4. Numerical simulation

4.1. Design schemes of the backfilled technology

The reserved coal pillar is important for the roof stability of the gob because it directly affects the backfilling effect (Ashok Jaiswal and Shrivastva 2009; Singh et al. 2011). Therefore, reasonable design of the coal pillar width is key in the backfilling process. Small coal pillars between gobs may cause rib convergence and a large area of roof caving, which in turn, will directly threaten people's safety (Ghasemi et al. 2012). In contrast, large coal pillars will lead to a lower recovery ratio of coal, wasting resources and resulting in low economic efficiency. Thus, a key task is to determine the appropriate width of the coal pillar. According to practical field experience and the stress state of the coal pillar in the working face, four schemes were proposed to determine the coal pillar width (Fig. 9): (a) 11 m mining width, 2 m coal pillar width; (b) 11 m mining width, 3 m coal pillar width; (c) 11 m mining width, 4 m coal pillar width; and (d) 11 m mining width, 5 m coal pillar width.

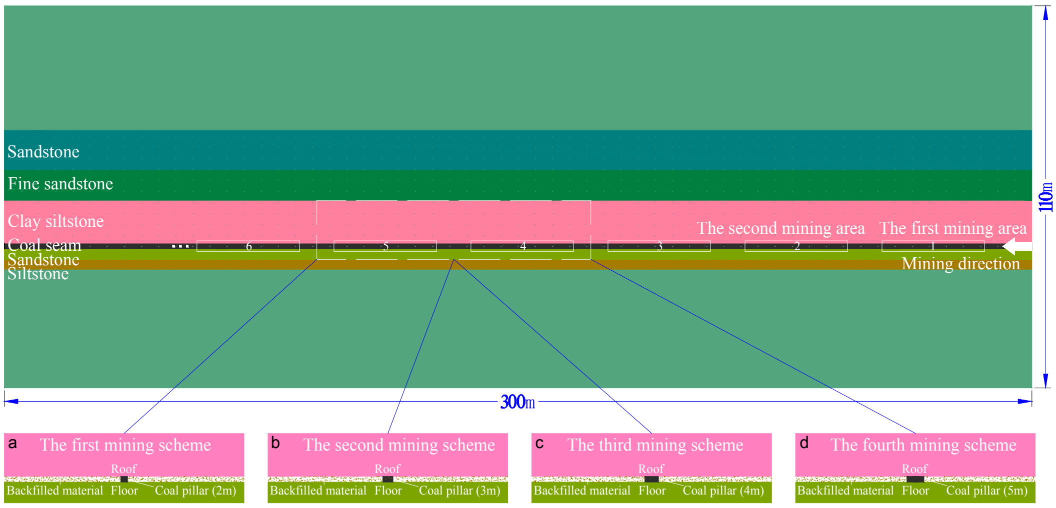
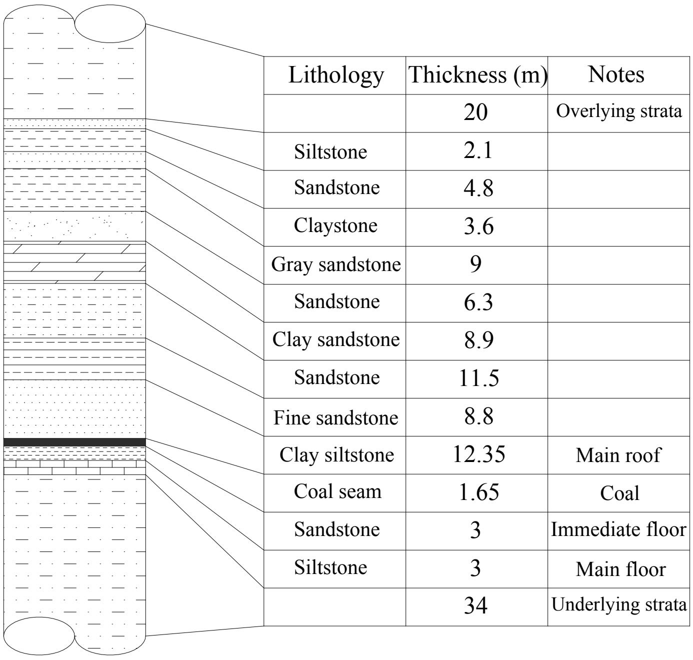


Fig. 9. Four design schemes of the backfilled technology

Rys. 9. Cztery schematy projektowe technologii podsadzki

A numerical model with fixed horizontal displacement at four sides and fixed vertical displacement at the bottom was conducted using FLAC^{3D} numerical simulation software to investigate the plastic zone development, stress state and the stability of the coal pillar. Based on the stratigraphy condition of the 9100 working face (Fig. 10), the numerical model covers an area of 300 × 175 m, 110 m in height (Fig. 8). To simulate a 150 m overburden load, a vertical compressive stress of 3.75 MPa was imposed on the top of the model by assuming the overlying unit weight to be 0.025 MN/m^3, and the gravity force was also applied. The Strain-Softening failure criterion was selected for the numerical simulation. The rock and coal property values used in this simulation are listed in Table 1, these values were selected from the geological report and the results of experimental tests. The stress changes of the rock formation after each excavation cycle were recorded by a monitoring line in the roof of the M9 coal seam.



Lithology	Thickness (m)	Notes
	20	Overlying strata
Siltstone	2.1	
Sandstone	4.8	
Claystone	3.6	
Gray sandstone	9	
Sandstone	6.3	
Clay sandstone	8.9	
Sandstone	11.5	
Fine sandstone	8.8	
Clay siltstone	12.35	Main roof
Coal seam	1.65	Coal
Sandstone	3	Immediate floor
Siltstone	3	Main floor
	34	Underlying strata

Fig. 10. Generalized stratigraphy of the 9100 working face of the Anshun coal mine

Rys. 10. Uogólniona stratygrafia 9100 przodków roboczych w kopalni Anshun

Table 3. Coal and rock mass properties

Tabela 3. Właściwości węgla i skał

Lithology	Density [kg/m^3]	Bulk modulus [GPa]	Shear modulus [GPa]	Friction angle [°]	Cohesion [MPa]	Tensile strength [MPa]
Overlying strata	2 500	6.00	5.00	30	2.00	1.50
Siltstone	2 600	4.30	3.56	34	3.32	2.75
Sandstone	2 650	4.95	3.90	36	3.50	3.60
Clay stone	2 200	2.50	1.75	27	1.80	2.00
Gray sandstone	2 580	4.05	3.26	34	3.35	3.30
Clay sandstone	2 550	3.84	3.19	33	3.13	3.21
Sandstone	2 650	4.95	3.90	36	3.50	3.60
Fine sandstone	2 630	4.87	3.85	35	3.45	3.58
Clay siltstone	2 590	4.12	3.20	32	3.20	2.50
M9 coal seam	1 400	1.05	0.55	23	1.20	0.90
Underlying strata	2500	6.00	5.00	30	2.00	1.50

4.2. Simulation result analysis

The results of vertical stress and vertical displacement were obtained in the process of numerical simulation. The results of four different design schemes for reserved coal pillars with widths of 2, 3, 4 and 5 m are shown in Fig. 11. It is observed that the maximal vertical stress can be determined as 14.3, 15.55, 13.44 and 12.49 MPa for 2, 3, 4 and 5 m, respectively. The vertical stress distribution was significantly influenced by the reserved coal pillar. However, mind out areas were in the state of lower stress because the overlying strata had finished their movement; the minimal vertical stress was 5.574, 5.679, 5.589 and 5.579 MPa for 2, 3, 4 and 5 m, respectively. Regarding vertical displacement, the results indicated that the maximal vertical displacement was 44.61, 80.18, 61.65 and 42.39 mm for 2, 3, 4 and 5 m, respectively. In addition, due to the supporting effect of the coal pillar, the roof near the coal pillar had a smaller vertical displacement, determined as 32.67, 44.92, 41.36 and 31.33 cm for 2, 3, 4 and 5 m, respectively.

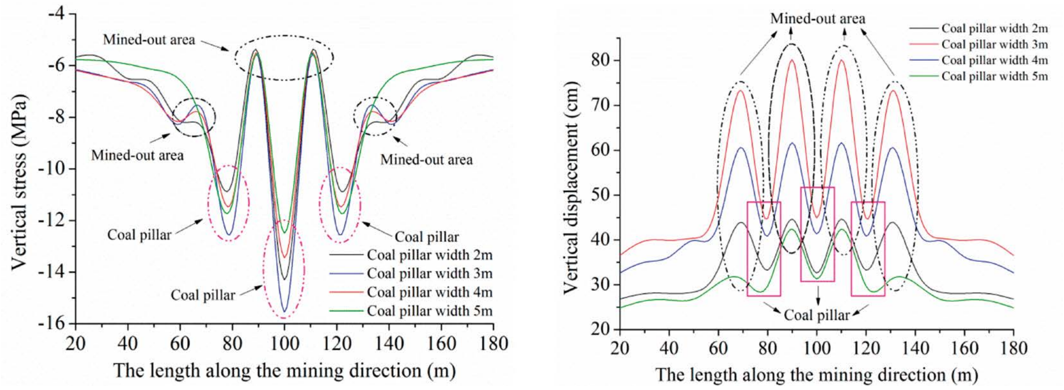


Fig. 11. Vertical stress and vertical displacement of a coal pillar after the fourth mining stage

Rys. 11. Naprężenia pionowe i pionowe przemieszczenie filaru węglowego po czwartym etapie wydobycia

Considering the vertical stress and vertical displacement, the coal pillars with widths of 2 m and 5 m can satisfy the stability requirement by taking the practical situation of the 9100 working face into account. The stability of the coal pillar and its stressing state are important to support the roof, thus indirectly affecting the backfilling mining process. To determine the width of the coal pillar, the plastic zones of coal pillars with widths of 2 m and 5 m were determined.

Fig. 12 shows the failure process of the coal pillar. The gradual failure of a coal pillar under uniaxial compression began from the boundary towards the center. When the compressive value reached the actual stressing state of coal pillar, an unbroken core, which can be defined as an elastic core still remains (Wang et al. 2013). The elastic core plays a significant

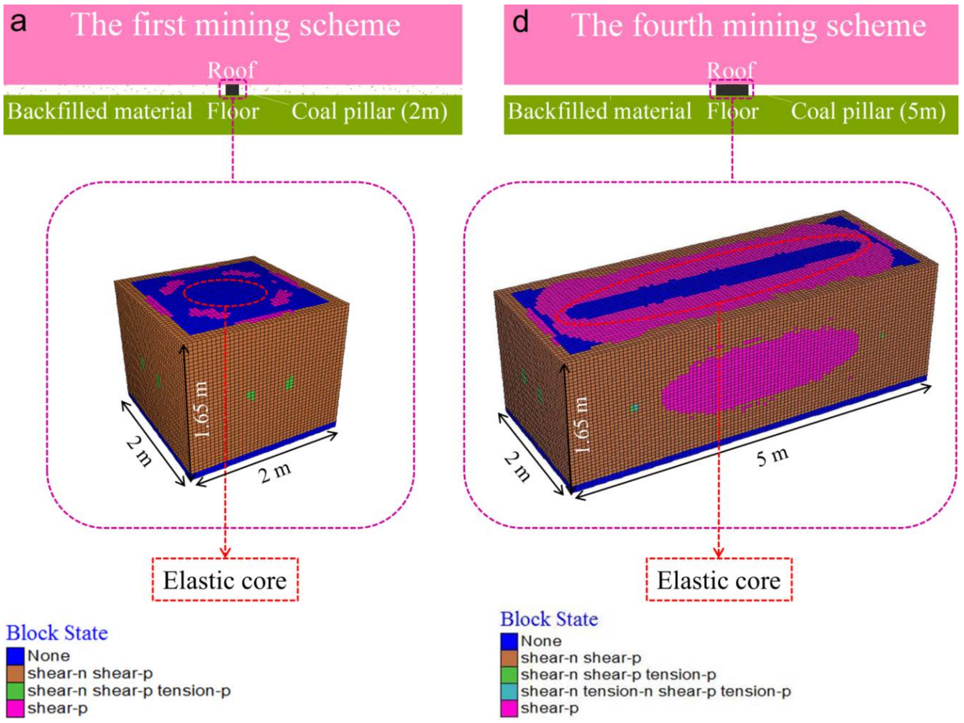


Fig. 12. Plastic zone of coal pillars: a) 2 m; b) 5 m

Rys. 12. Strefa plastyczności filarów węglowych; a) 2 m, b) 5 m

role in the loading capacity of a coal pillar, and it also a key factor that is closely related to the supporting effect (Wang et al. 2011). The elastic core was found in the coal pillars with widths of 2 m and 5 m, indicating that the coal pillar with widths of 2 m and 5 m both had supporting effects on the overlying strata. Therefore, to achieve a higher recovery rate of coal and better economic efficiency, the coal pillar with a width of 2 m was selected.

5. Engineering practice effect analysis

5.1. Application effect analysis

The 9100 working face that adopted the integrated treatment technology was mined for approximately 340 m. To investigate the treatment effect on the surface sinkhole and the ground fissures in the Anshun coal mine, the surface sinkhole movement observation stations were set in the corresponding positions in the process of coal mining. The monitoring line for measuring the ground movement was arranged along the direction from SE to NW (Fig. 2) using a total of four monitoring points: A1, A2, A3 and A4. The monitoring occurred from March 28, 2015 to December 28, 2015. The monitoring results for the surface sinkhole were collected to evaluate the effect of the integrated treatment technology.

The results indicated that the maximal deformation is 17.3 cm, the ground fissures clearly decreased, and the surface buildings are in a state of rare destruction (Fig. 13). The analysis results revealed that the ground surface basically had no evident deformation after the integrated treatment technology was adopted.

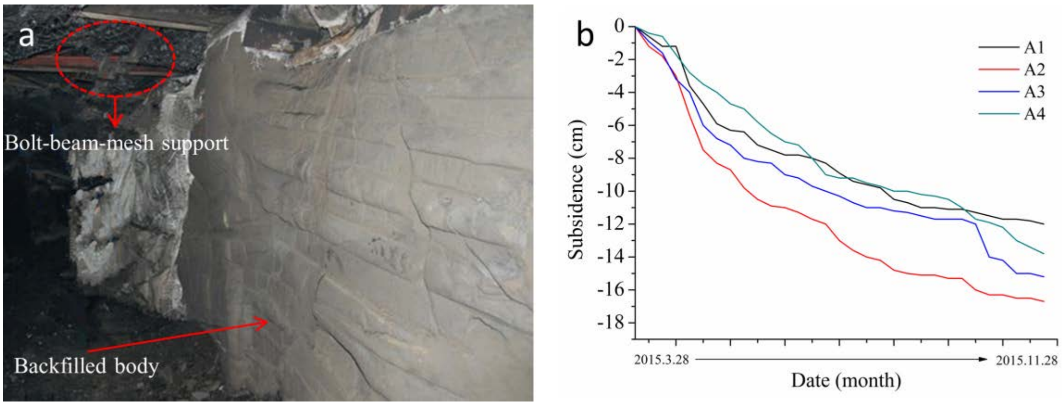


Fig. 13. Effect of the united treatment technology
a) underground field scene of backfilled effect; b) the ground sinkhole deformation

Rys. 13. Wpływ technologii zabiegu
a) efekt podsadzki, b) deformacja pęknięć gruntu

5.2. Economic and environmental benefits

When the 9100 working face of the Anshun coal mine adopted the integrated treatment technology, the ground fissures were effectively controlled, and the fissures in buildings disappeared, thereby ensuring the residents' personnel safety. Therefore, the Anshun coal mine greatly reduced the cost of moving residents, resulting in an indirect economic benefit of CNY 3.26 million per year. After we treated the ground fissures and planted vegetation, the vegetation coverage of the coal mining area increased by 42.3%. The ground surface remains stable because of the better effect of the ground fissure treatment technology, with the vegetation survival rate reaching an average value of 85%. In addition, coal gangue and fly ash are effectively used. According to statistical data, the treatment capacity of coal gangue and fly ash reached 821.150 t per year. In other words, the integrated treatment technology has achieved a "bilateral winning strategy", i.e., this action not only protected the ecological environment but also realized the full utilization of coal mine solid wastes. The use of the integrated treatment technology is in accord with the theme of green mining and scientific mining. Thus, the successful application of integrated treatment technology in the Anshun coal mine provides useful reference material for other coal mines in the southwestern coal mining area of China.

Conclusion

Mining activities in southwestern China often cause ground fissures, surface sinkhole, vegetation deterioration and other environmental problems. Integrated treatment technology, which includes ground surface fissure treatment technology and underground backfilled technology, was first used in the Anshun coal mine to fully utilize coal mine solid wastes and enable environmental protection in a mining area. Experimental results of uniaxial compression on backfilled material samples with different mixing ratios of 1:0.1:0.16, 1:0.3:0.18 and 1:0.5:0.22 indicated that the mixture of coal gangue, fly ash and ordinary Portland cement with a ratio of 1:0.3:0.18 was the desired backfilled material because of the maximal compressive strength. Vertical stress, vertical displacement and the plastic zone of the coal pillar were analyzed by using FLAC3D numerical simulation. The reasonable mining scheme of "11 m mining width, 2 m coal pillar width" was determined because of the lower vertical stress of 14.3 MPa, the vertical displacement of 32.67 cm and the better supporting capacity of the coal pillar.

After adopting the integrated treatment technology in the 9100 working face, the maximal ground sinkhole deformation is 17.3 cm, and the vegetation survival rate of ground fissures treatment area reached 85%; thus, this technology effectively controlled surface sinkhole and ground fissures. With its economic and environmental benefits, this technology can provide references for coal mines in the southwestern area of China.

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REFERENCES

Adibee et al. 2013 – Adibee, N., Osanloo, M. and Rahmanpour, M. 2013. Adverse effects of coal mine waste dumps on the environment and their management. *Environmental Earth Sciences* (70), pp. 1581–1592.

Ashok, Jaiswal and Shrivastva, B.K. 2009. Numerical simulation of coal pillar strength. *International Journal of Rock Mechanics and Mining Sciences* 46, pp. 779–788.

Bell, F.G. and Genske, D.D. 2001. The influence of subsidence attributable to coal mining on the environment,development and restoration:Some examples from Western Europe and South Africa. *Environmental & Engineering Geoscience* 7(1), pp. 81–99.

Bian et al. 2010 – Bian, Z.F., Miao, X.X., Lei, S.G., Chen, S.E., Wang, W.F. and Struthers, S. 2010. The Challenges of Reusing Mining and Mineral-Processing Wastes. *Science* 337, pp. 702–704.

Dai et al. 2014 – Dai, H.Y., Guo, J.T., Yan, Y.G., Li, P.X. and Liu, Y.S. 2014. Principle and application of subsidence control technology of mining coordinately mixed with backfilling and keeping. *Journal of China Coal Society* 39(8), pp. 1602–1610.

Fabiańska et al. 2013 – Fabiańska, M.J., Ciesielczuk, J., Kruszewski, Ł., Misz-Kennan, M., Blake, D.R., Stracher, G. and Moszumańska, I. 2013. Gaseous compounds and efflorescences generated in self-heating coal-waste dumps – A case study from the Upper and Lower Silesian Coal Basins (Poland). *International Journal of Coal Geology* 117, pp. 247–261.

Ghasemi et al. 2012 – Ghasemi, E., Ataei, M., Shahriar, K., Sereshki, F., Jalali, S.E. and Ramazanzadeh, A. 2012. Assessment of roof fall risk during retreat mining in room and pillar coal mines. *International Journal of Rock Mechanics and Mining Sciences* 54, pp. 80–89.

Guo et al. 2014 – Guo, Y.X., Zhang, Y.Y. and Cheng, F.Q. 2014. Industrial development and prospect about comprehensive utilization of coal gangue. *CIESC Journal* 65(7), pp. 2443–2453.

Huang et al. 2015 – Huang, Y., Tian, F., Wang, Y., Wang, M. and Hu, Z. 2015. Effect of coal mining on vegetation disturbance and associated carbon loss. *Environmental Earth Sciences* (73), pp. 2329–2342.

Hui et al. 2016 – Liu. H., Liu. X.Y., Deng. K.Z., Lei S.G. and Bian, Z.F. 2016. Developing law of sliding ground fissures based on numerical simulation using UDEC. *Journal of China Coal Society* 41(3), pp. 625–632.

Liu et al. 2012 – Liu, G.L., Fan, K.G. and Xiao, T.Q. 2012. Research on Working Resistance of Mining Working Face in Mountainous Buried Coal Seam. *Chinese Journal of underground space and engineering* 8(8), pp. 1034–1040.

Li et al. 2017 – Li, L., Wu. K., Hu. Z., Xu, Y. and Zhou, D. 2017. Analysis of developmental features and causes of the ground cracks induced by oversized working face mining in an aeolian sand area. *Environmental Earth Sciences* 76(3), pp. 1–12.

Mohseni et al. 2017 – Mohseni, N., Sepehr, A., Hosseinzadeh, S.R., Golzarian, M.R. and Shabani, F. 2017. Variations in spatial patterns of soil–vegetation properties over subsidence-related ground fissures at an arid ecotone in northeastern Iran. *Environmental Earth Sciences* 76(6), pp. 1–13.

Ning, C.X. 2017. China coal production structure prediction in 2030 based upon Markov chain. *China coal* 1(43), pp. 11–15.

Singh et al. 2011 – Singh, A.K., Singh, R., Maiti, J., Kumar, R. and Mandal, P.K. 2011. Assessment of mining induced stress development over coal pillars during depillaring. *International Journal of Rock Mechanics and Mining Sciences* 48(5), pp. 805–818.

Tan et al. 2017 – Tan, W., Wang, L. and Huang, C. 2017. Environmental Effects Environmental effects of coal gangue and its utilization. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 38(24), pp. 3716–3721.

Wang et al. 2011 – Wang, H.W., Poulsen, Brett A., Shen, B.T., Xue, S. and Jiang, Y.D. 2011. The influence of roadway backfill on the coal pillar strength by numerical investigation. *International Journal of Rock Mechanics and Mining Sciences* 48(3), pp. 443–450.

Wang et al. 2013 – Wang, H.W., Jiang, Y.D. and Zhao, Y.X. 2013. Numerical Investigation of the Dynamic Mechanical State of a Coal Pillar During Longwall Mining Panel Extraction. *Rock Mechanics & Rock Engineering* (46), pp. 1211–1221.

Yang et al. 2016 – Yang, Z., Zhang, Y., Liu, L., Wang, X. and Zhang, Z. 2016. Environmental investigation on co-combustion of sewage sludge and coal gangue: SO_2 , NOx and trace elements emissions. *Waste Management* 50(x), pp. 213–221.

Zhang et al. 2014 – Zhang, Q., Zhang, J.X., Ju, F., Li, M. and Geng, D.K. 2014. Backfill body's compression ratio design and control theory research in solid backfill coal mining. *Journal of China Coal Society* 39(1), pp. 64–71.

Zhou, W.X. and Chen, X.Y. 2014. A case study on Bijie city: Relation between coal enriching areas and economic growth. *Resources & industries* 16(3), pp. 132–136.

Zhu et al. 2014 – Zhu, H.Z., Liu, P. and Song, G.P. 2014. Field test research on large amplitude mountain shallow buried coal seam pressure behavior. *Science Technology and Engineering* 28(14), pp. 195–199.

ZINTEGROWANA TECHNOLOGIA ZAPOBIEGANIA PĘKNIĘCIOM GRUNTU W PROCESIE WYDOBYWANIA PŁYTKICH POKŁADÓW WĘGLA W GÓRZYSTYM OBSZARZE POŁUDNIOWO-ZACHODNICH CHIN: TYPOWE STUDIUM PRZYPADKU

Słowa kluczowe

wydobywanie płytkich pokładów węgla, pęknięcia gruntu, zapadliska,
zintegrowana technologia zapobiegania, ochrona środowiska

Streszczenie

Artykuł jest opisem zapobiegania pęknięciom gruntu w celu ochrony środowiska, jak również naukowego podejścia do wydobywania płytko zalegających pokładów węgla. W południowo-zachodniej części górniczej Chin tradycyjna, ścianowa metoda wydobywania węgla, powodowała duży obszar powierzchniowego zapadliska, pęknięcia gruntu, pogorszenie stanu wegetacji roślin. W celu rozwiązania tych problemów zaproponowano zintegrowaną technologię zapobiegania, która obejmuje technologię zapobiegania pęknięciom gruntu i podziemną technologię podsadzki. Zasada i proces techniczny zostały szczegółowo opisane; technologia zapobiegania pęknięciom gruntu obejmuje „trójstopniową metodę zabiegu", a technologia podsadzki zaadoptowała metodę wydobywania węgla pasami. Badano ściśliwość podsadzki, w tym odpadów węglowych, popiołu lotnego i zwykłego cementu portlandzkiego; wybrano mieszaninę o stosunku 1: 0,3: 0,18. Ponadto pionowe naprężenie, pionowe przemieszczenie i strefa plastyczności filaru węglowego zostały określone za pomocą symulacji numerycznej FLAC 3D. Racjonalny schemat wydobycia „szerokość wydobycia 11 m, szerokość filaru węglowego 2 m" był odpowiedni ze względu na niższą wartość naprężenia pionowego, mniejsze pionowe przemieszczenie i lepszą nośność filaru węglowego. Wyniki monitoringu pęknięć gruntu wskazują, że maksymalna deformacja gruntu wynosiła 17,3 cm i wykazała kilka zmian po wdrożeniu tej technologii. Ilość zagospodarowanych odpadów węglowych i popiołu lotnego wynosiła 821 150 Mg na rok, a wskaźnik przeżycia roślinności w obszarze zapobiegania pęknięciom gruntu osiągnął poziom 85%. Ta zintegrowana technologia zapobiegania może skutecznie kontrolować pęknięcia gruntu i deformację powierzchni, a także chronić środowisko.

AN INTEGRATED TREATMENT TECHNOLOGY FOR GROUND FISSURES OF SHALLOW COAL SEAM MINING IN THE MOUNTAINOUS AREA OF SOUTHWESTERN CHINA: A TYPICAL CASE STUDY

Keywords

shallow coal seam mining, ground fissures, surface sinkhole, integrated treatment technology, environmental protection

Abstract

This article is the result of treatments on ground fissures for environmental protection and scientific shallow coal seam mining. In the southwestern mining area of China, the traditional longwall mining method has caused a large area of surface sinkhole, ground fissures, vegetation deterioration and disorderly coal gangue. To solve these problems, an integrated treatment technology that includes ground fissure treatment technology and underground backfilled technology was proposed as a solution. The technical principle and technical process were explained in detail; the ground fissure treatment technology involves a "three-step treatment method", and the underground backfilled technology adopted a strip mining method with backfilling technology. The compression mechanical behavior of backfilled material, including coal gangue, fly ash and ordinary Portland cement, was studied; the mixed ratio of 1:0.3:0.18 was selected. In addition, the vertical stress, vertical displacement and plastic zone of the coal pillar were determined by FLAC3D numerical simulation, and a rational mining scheme of "11 m mining width, 2 m coal pillar width" was determined to be appropriate because of the lower vertical stress, smaller vertical displacement and better supporting capacity of the coal pillar. The monitoring results of ground sinkhole indicated that the maximal ground sinkhole deformation was 17.3 cm, and the deformation showed few changes after this technology was implemented. The treatment capacity of coal gangue and fly ash reached 821.150 t per year, and the vegetation survival rate of the ground fissure treatment area reached 85%. This integrated treatment technology could effectively control ground fissures and surface sinkhole as well as protect the environment.