ISSN 2706-655X Vol.5, Issue 1: 48-56, DOI: 10.25236/IJFET.2023.050108

Study on in-road filling without coal pillar mining technology and its material proportioning optimization

Di Wu

College of Energy and Mining Engineering, Shandong University of Science and Technology, Qingdao, Shandong, 266590, China

Abstract: *In order to solve the problems of low extraction rate of coal resources and pollution of mine gangue solid waste, based on the in-road paste filling without coal pillar mining technology, a coal mine in Shandong underground working face transport road as the research object, through theoretical analysis to determine the in-road filling body parameters, in order to explore the excellent load-bearing performance, low cost of filling gangue paste in-road filling material, combined with laboratory tests on the paste filling material ratio and mechanical properties for Ratio optimization study, the optimal filling material ratio of cement: fly ash: coal gangue = 1:2:5, mass concentration of 78%, early strength agent admixture of 1.6%. Under the condition of this ratio, the early strength of the filling specimen can reach 2MPa, and the late strength can reach 14MPa, and the specimen still has high residual strength after compression damage, and the support resistance is considerable and the bearing performance is good.*

Keywords: *No pillar mining; Paste filling in roadway; Ratio optimization; Orthogonal test*

1. Introduction

The continual exploitation of humans will result in dwindling coal reserves because it is a non-renewable resource. A significant amount of coal resource are lost due to the conventional design strategy, which typically involves leaving protective coal pillars between neighboring working faces. One of the main issues facing coal industry to achieve sustainable development is improving the recovery rate of coal resource. [1-2]

Along the air stay lane, along the air dug lane roadway technology has become a new idea and effective way to improve the resource recovery rate and extend the service life of the mine in each mine. Along the air stay lane is affected by two mining activities of the upper section and the over-support pressure of this section, and the maintenance of the lane is difficult, especially in the comprehensive mining of medium-thick coal seam, it is more difficult to use along the air stay lane and the cost of lane protection is high. Along the airway is to dig the roadway in the lateral support pressure reduction zone after the influence of the upper section workings tends to stabilize (leaving small coal pillar or no coal pillar), the roadway only undergoes one mining influence, and is easier to maintain. [3-6]Along the empty roadway technology can be borrowed from the special rock structure formed by the previous workings, so as to improve the stability of the surrounding rock of the retrieval roadway, no coal column along the empty roadway due to the large amount of residual gas, water and the overall instability of the falling gangue in the mining area, causing serious impact on the normal tunneling of the roadway, generally non-special geological conditions of the mine should not be used. Narrow coal pillar along the empty roadway through the calculation of the effective width of the narrow coal pillar, and in the narrow coal pillar stress reduction zone for the roadway layout, its main feature is the roadway surrounding rock stress is small, can be effective control of the roadway surrounding rock deformation, along the empty roadway generally difficult to achieve no coal pillar mining, need to leave about 3 ~ 6m narrow coal pillar protection roadway, will still lose more coal resources, so the use of no coal pillar protection roadway has a very important Therefore, it is very important to adopt coal-free pillar protection road. [7-9]

Coal mining and coal processing operations, the amount of coal gangue solid waste generated each year accounts for 10% to 25% of coal production, the cumulative amount of gangue piled up in China is more than 6 billion tons. Gangue discharge pollution problem is very serious, a large number of gangue long-term storage, occupy the land, pollution of water quality, the ecological environment caused great damage. Gangue paste filling material support has a fast speed, support resistance, filling process is simple and other excellent performance. Therefore, the use of gangue paste filling material filling construction filling body replacement coal column, not only can improve the coal resources extraction rate, improve the safety production conditions, but also can deal with gangue pollution. [10-12]

The study of in-road paste filling without coal pillar mining technology and its filling material ratio optimization is important for gangue not to rise well, reduce the cost of gangue disposal, improve the recovery rate of mine resources and enhance the economic benefits of the mine, filling mining technology as an important part of the "green mining system" is an important technical means to achieve sustainable development of coal mine production.

2. No coal pillar mining technology with paste filling in roadway

2.1 Technical principle of non pillar mining with paste filling in roadway

The in-road paste-filled column-free mining technology can reduce the loss of coal columns in the mining section of medium-thick coal seams. In other words, when the working face of the upper section is dug into the flat road, the coal wall of the next section is expanded, and the coal is filled in the expanded area, and the flat road of the working face is dug along the wall of the filling body, so that there is no need to keep the coal pillar, and the coal pillar of the original adjacent working face is replaced by the wall of the filling body, so as to realize the pillar-free mining of the working face of the medium-thick coal mine.

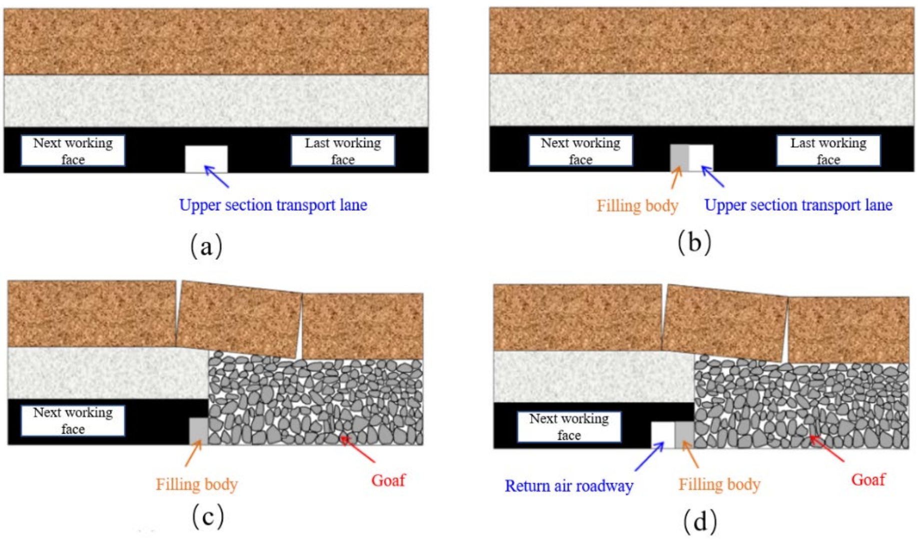

Figure 1: The paste filling in the roadway without coal pillar excavation steps

As shown in Figure 1, the steps of the technology of roadway excavation without coal pillar with paste filling in the roadway are as follows: (a)When the upper section working face is tunnelling, the wall shall be expanded, and the position of the filling body in the roadway shall be reserved; (b)The filling work shall be carried out in the roadway to construct the filling body, and the strength of the filling body shall meet the stability of the upper working face in the mining stage, the working face in the driving stage without coal pillars, and the working face in the mining stage at the same time; (c)The upper working face is mined; (d) After the overburden of the upper working face is basically stable, the drift of the working face will be excavated along the filling body.

2.2 Characteristics of non pillar mining technology with paste filling in roadway

(1) Compared with gob side entry retaining, the pre placed filling wall in the roadway has lower requirements on the early strength of the filling wall, and is independent of the mining work, so it will not affect the production progress of the mine.

(2) The transportation roadway of the upper section working face and the air return roadway of the lower section working face serve only one working face, and the service time is short, which can reduce the support and maintenance costs of the roadway.

(3) When the working face in the upper section is mined, one side of the transport roadway is solid coal. When the working face in the lower section is mined, one side of the air return roadway is a goaf with stable caving. The filling body is always within the range of "small structure", which is conducive to the stability of the filling body.

(4) The strength and width of the filling body can be set manually. Before mining, the filling body parameters can be designed in advance according to the geological conditions. In general, protective coal pillars are reserved for tunneling. The strength of the coal pillars is low, and it needs to spend manpower and material resources to reinforce them during the mining process. The process is complicated, and a lot of coal resources are wasted.

2.3 Stability analysis of coal-free pillar mining roadways

The overburden rock of the roadway is directly topped by the roadway and acts on the roadway. When the workings are retrieved, the overburden rock collapse, fracture characteristics and the state of survival after spanning depends mainly on the fracture characteristics of the key layer and the state of survival after spanning. The arch-shaped "big structure" formed after the overlying rock layer gradually stabilises after mining, which directly affects the stability of the lower roadway and the filling body. In general, the impact of the tunneling of the roadway along the open cut on the stability of the "big structure" is minimal, therefore, before and after the tunneling of the backhoe roadway at the working face of the section, the backhoe roadway and the filling body are under the protection of the "big structure", and generally speaking, its stability is relatively good.

After the key block B is formed, it starts to rotate and sink, and the weight of the overlying rock layer on the basic roof is gradually transferred to the coal body of the roadway gang through the direct roof, and stress concentration appears on the coal body of the roadway gang. As the key block B rotates and sinks, the key block B forms a "large structure" under the joint action of the fallen gangue in the quarry area, the roadside filler, the direct roof and the coal body of the roadside, if the key block B is in a stable state, the roadway will be under the protection of the key block, and the surrounding rock stress along the hollow stay in a certain range will be much lower than the original rock stress. The overlying rock structure of the roadway can remain stable before and after the roadway is dug, but when the section is re-mined, the key block in the overlying rock structure will have a certain degree of rotary sinking movement, but will not be destabilised, which is beneficial to control the deformation of the roadway surrounding rock, thus ensuring its stability.

3. Determination of fluidity index of paste backfill

The flow performance indexes of paste filling body include: stability of paste filling body slurry, pumpable time, setting time, etc. Slump index is generally used for slurry flow performance, while water secretion rate is usually used for slurry stability performance. As the main raw material gangue is piled on the ground, the slurry preparation needs to be completed in the filling station, and the prepared slurry will be transported to the goaf, which puts forward certain requirements for the fluidity of paste filling materials. According to the practical experience of other coal mines and the actual situation of coal mines, the requirements for its fluidity are mainly as follows:

(1) Slump

The fluidity of slurry is very important for filling operation, and usually the slump index is used to react. Because the slurry is transported by pumping, it should have enough slump when it is in the slurry state. The research shows that when the slump of paste slurry is less than 15cm, the resistance loss during transportation changes obviously with the increase of the slump. When the slump is greater than 15cm, the change gradually decreases. When the slump is greater than 18cm, the resistance loss tends to a certain value with the increase of the slump. Considering that if the paste pumping distance and pipeline wetting degree are different, there will be a certain slump loss, generally 1-2cm. In comprehensive consideration, the slump of the slurry into the pump shall not be less than 18cm. However, the greater the slump is, the better. It should be determined according to the actual pumping distance and pumping height. The slump should not exceed 25cm. In conclusion, the appropriate slump should be 18-25cm.

(2) Water secretion rate

The water secretion rate of paste filling slurry is one of the important performance parameters in paste filling engineering, especially for long-distance paste slurry pumping. If the water secretion rate of paste slurry is large, segregation will occur during transportation, and the aggregate will sink and water will float during transportation, leading to blockage in the pipeline. In order to ensure the stability of the paste, make sure that the paste filling materials will not be layered, separated and precipitated even if the transportation is interrupted for a long time, and minimize the environmental pollution of the working face caused by bleeding and the filling failure caused by bleeding. The slurry should have a low bleeding rate. Generally, the standing water secretion rate should be less than 3%.

4. Study on the Proportioning of Waste Gypsum Filling Materials

The research on the mechanical properties of the filling material and its influencing factors belongs to the important content and one of the key technologies of coal mine roadway filling along the hollow roadway, so the stability of the filling body is one of the main influencing factors of the stability of the surrounding rock along the hollow roadway, which will be described in terms of filling material selection, material ratio test and material ratio optimization.

4.1 Paste filling material in roadway

The common filling materials used in underground coal mines can be divided into three categories: inert materials, cementitious materials and modified materials. According to a mine site engineering conditions, it is proposed to determine the underground inert materials for coal gangue, cement and fly ash for cement, and add other modified materials such as early strength agent, and finally add an appropriate amount of water and according to a certain ratio to make the roadway filling materials.

(1) Coal gangue

The chemical composition of test coal gangue is shown in Table 1, and the most important components are SiO_2 and Al_2O_3. Gangue is mainly used as aggregate, and it shall be broken according to the standard before being used, and the maximum particle size shall not exceed 25mm after being broken. The screening test was carried out in the laboratory. The particle size of most of the test gangue was 0.1-16mm, a small amount was 20mm, 5-25mm accounted for 45%, and the part less than 5mm accounted for 55%. This basically met the requirement that the maximum particle size of the gangue in the preparation of paste filling materials should not exceed 25mm, and the proportion of the part less than 5mm should reach about 40%. The particle size distribution is shown in Figure 2.

Table 1: Main chemical composition of coal gangue

Chemical composition	SiO_2	Al_2O_3	CaO	Fe_2O_3	Na_2O	K_2O	MgO	Firing loss
Mass ratio (%)	58.8	18.8	2.36	4.2	0.51	2.09	1.63	14.7

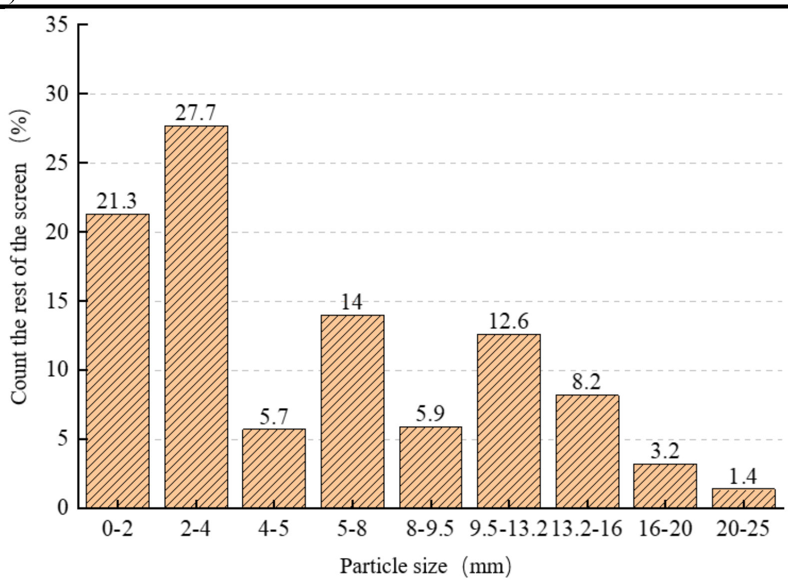

Figure 2: Particle size distribution of gangue after crushing

ISSN 2706-655X Vol.5, Issue 1: 48-56, DOI: 10.25236/IJFET.2023.050108

(2) Cement

Cement content is a very important parameter in the design of filling slurry ratio, which not only determines the final compressive strength of the filling body, but also greatly affects the cost of filling. The cement selected for the test is P.O42.5 Portland cement produced by a cement factory in Qingdao. Its important reaction elements are tricalcium silicate and dicalcium silicate. Its chemical composition is shown in Table 2. When the cement and water are fully mixed, the internal compounds will undergo hydration reaction, causing the cement slurry to harden.

Table 2: Main chemical composition of cement

Chemical composition	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3
Mass ratio (%)	61.48	22.95	5.61	4.20	2.46	2.44

(3) Fly ash

Fly ash is the fine powder collected from the boiler flue gas of coal-fired thermal power plants. It is the main solid waste discharged by thermal power plants and thermal power plants. According to the fineness and burning loss of fly ash, fly ash used as concrete and mortar admixture is divided into three grades in China. The average uniaxial compressive strength of the filling body specimen will increase after adding fly ash. In addition to replacing part of the cement with fly ash, adding a certain proportion of fly ash to the paste filling slurry can reduce the pipeline transmission resistance, enhance the pumping performance of the paste material, and also enhance the later strength of the filling body, but it has little effect on the initial strength of the filling body.

(4) Admixture

Early strength agent and water reducing agent are usually used as high efficient additives in paste filling of gob side entry retaining. The early strength agent mainly uses its chemical reaction with the cement to improve the hydration reaction and hardening rate of the cement. Shortening the setting time and enhancing the early strength of the backfill are the main functions of the early strength agent, which does not affect its late strength in this process. The water reducing agent relies on the principle of same-sex repulsion to make the cement particles charged and repel and disperse, thus releasing excess water to complete the water reducing effect; Secondly, the water reducer can compact the cement network structure, improve the surface of cement particles, and improve the strength and compaction performance of the backfill.

4.2 Study on Optimization of the Proportion of Waste Gypsum Filling Materials

4.2.1 Test scheme design

As the most common method in multi-element and multi-level research, orthogonal experimental design selects typical factors from the influencing factors to carry out experiments, so that the various factors are evenly distributed and the most accurate results can be obtained with the minimum number of experiments, which has the advantage of being efficient, fast and comprehensive.

The following factors were used in this orthogonal test: gangue to cement mass ratio A, fly ash to cement mass ratio B, mass concentration of slurry C, early strength agent addition D. Gangue to cement mass ratio was taken from 4 to 6, fly ash to cement mass ratio 1 to 3, mass concentration was taken from 78 wt.% to 82 wt.%, and early strength agent addition was 1.6% to 2%. Each factor was taken at three levels, and a total of nine tests were conducted. The indexes under investigation include collapse, water secretion rate, setting time and uniaxial compressive strength, and the orthogonal test factor levels are shown in Table 3, and the proportional test design is shown in Table 4.

Table 3: Horizontal table of orthogonal test factors

Level	Factor A	Factor B	Factor C	Factor D	Water reducing agent
	Gangue:Cement	Fly ash:Cement	Mass concentration (wt.%)	Early strength agent (wt.%)	
1	4	1	78%	1.6%	1%
2	5	2	80%	1.8%	1%
3	6	3	82%	2%	1%

Table 4: Orthogonal test proportioning design table

Test number	Influencing factor			
	Gangue:Cement	Fly ash:Cement	Mass concentration (wt.%)	Early strength agent (wt.%)
1#	4	1	78%	1.6%
2#	4	2	80%	1.8%
3#	4	3	82%	2%
4#	5	1	80%	2%
5#	5	2	82%	1.6%
6#	5	3	78%	1.8%
7#	6	1	82%	1.8%
8#	6	2	78%	2%
9#	6	3	80%	1.6%

4.2.2 Test process

The test process mainly includes slurry configuration, collapse test, setting time test, water secretion rate test, slurry mold construction, mold release and maintenance, compressive strength test. After mixing all materials according to the ratio, the slurry was obtained, and the tests of collapse, water secretion rate and setting time were carried out first, and the remaining slurry was loaded into the mold, shaken evenly and waited for solidification. The uniaxial compressive strength test was carried out for 1d, 7d, 14d and 28d specimens according to the test standard using a digital display type pressure tester. After adjusting the compressive strength test parameters and running, the specimens were continuously loaded at a rate of 0.01mm/s until they were damaged, and the damage load and peak compressive strength values were recorded.

4.2.3 Test results and analysis

The tests yielded paste collapse and uniaxial compressive strength of the specimens as shown in Table 5. Nine sets of tests were conducted, and the transport properties (collapse, water secretion rate, setting time) were tested and recorded for some of the pastes during the preparation process. The remaining pastes were poured into the molds, and after the paste set and demolded for curing, the compressive strength was tested and recorded at each age (1d, 7d, 14d, 28d). The results of the orthogonal tests are shown in Table 5.

Table 5: Table of orthogonal test results

Test number	Bleeding rate (%)	Setting time (h)		Slump (cm)	Uniaxial compressive strength at different ages (MPa)			
		Initial setting	Final setting		1d	7d	14d	28d
1#	2.60	5.53	7.45	24	1.934	9.482	11.629	15.126
2#	2.72	5.2	8.02	19	1.842	6.236	9.252	13.951
3#	2.31	4.85	7.63	18	2.131	8.672	9.725	15.327
4#	2.44	4.82	7.41	13	1.963	5.947	7.542	14.271
5#	2.23	4.46	7.27	19	2.485	8.356	11.158	13.847
6#	2.76	5.22	7.91	21	1.523	5.865	8.952	14.587
7#	2.09	4.06	6.45	22	1.658	7.352	7.626	12.982
8#	2.66	4.64	7.51	24	1.969	6.166	9.588	13.861
9#	2.26	4.38	6.89	17	1.396	7.625	10.254	14.852

ISSN 2706-655X Vol.5, Issue 1: 48-56, DOI: 10.25236/IJFET.2023.050108

Table 6: Collapse range analysis table

k_i and R values	Slump			
	A	B	C	D
k_1	20.33	19.66	23	20
k_2	17.66	20.66	16.33	20.66
k_3	21	18.66	19.66	18.33
range R	3.33	2	6.66	2.33
factors	C-A-D-B			

The range analysis of the test results shows that the primary and secondary order of the factors affecting the slump is C>A>D>B through the analysis of Table 6 and Figure 3. Therefore, the main factor affecting the slump of the filling material is the mass fraction, while other factors have relatively little impact on the slump. Therefore, the C factor, i.e. mass concentration, should be the main consideration in selecting the optimum ratio for the collapse, with C1 being the optimum choice.

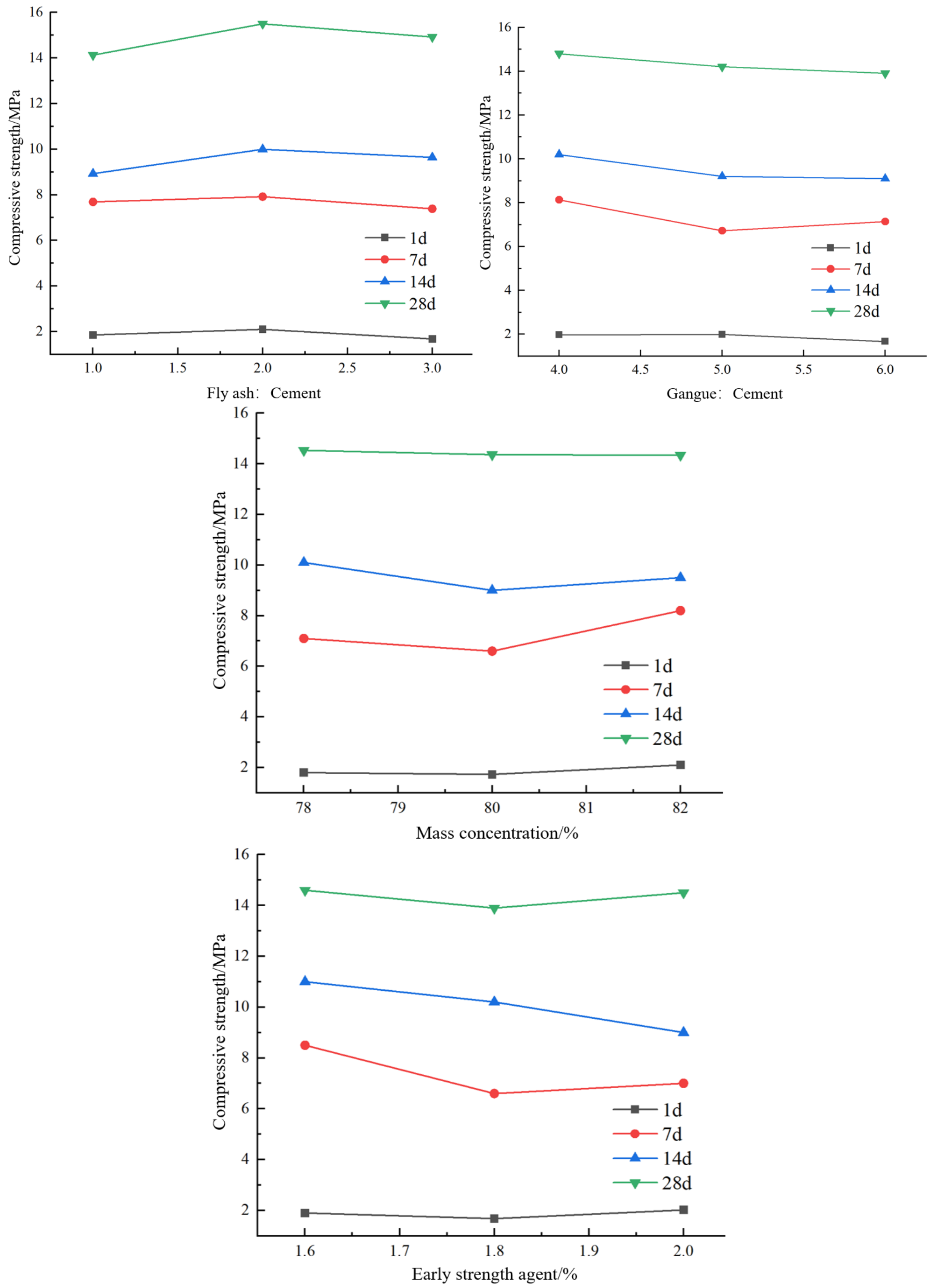

Figure 3: Compressive strength sensitive trend chart

ISSN 2706-655X Vol.5, Issue 1: 48-56, DOI: 10.25236/IJFET.2023.050108

(1) The primary and secondary order of influencing factors on compressive strength of paste filling material specimens of different ages is 1d: C-B-A-D; 7d: D-C-A-B； 14d:D-B-A-C； 28d:B-A-D-C。

(2) 1d compressive strength plays a major role in the influence of B and C factors; C factors have a greater impact on the strength before 7d, for 14d and 28d specimen strength is relatively small; 14d, D factors become the main factor of compressive strength, at this time the impact of C factors on the compressive strength of the specimen is relatively small; 28d B factors have the greatest impact on the strength.

(3) According to Figure 3, the compressive strength sensitivity trend shows that the compressive strength decreases with the increase of gangue cement mass ratio, and increases first with the increase of fly ash cement mass ratio and then decreases. It is obtained that with the increase of gangue and the decrease of cement, the strength of filling body gradually decreases, and with the increase of fly ash, the compressive strength appears to increase first and then decreases.

(4) Combined with the actual conditions of the coal working face without coal pillar digging and theoretical calculation of the strength requirements of the filling body in the roadway, it is necessary to optimize the screening of the ratio of the compressive strength of the filling material for the long-term age, and come up with a better combination of 28d strength, and then unify it with the better combination of collapse degree conditions, and then consider the primary and secondary role of the influencing factors of each age, and finally determine the optimal combination of factors as $A_2B_2C_1D_3$.☐

5. Conclusion

The paste body filling non-pillar mining technology in the roadway avoids the impact of the roadway being disturbed by twice mining, which can effectively improve the maintenance status of the Gobi side roadway, realize the sequential replacement of non-pillar between sections and improve the resource recovery rate. The filling material of gangue body has the characteristics of fast compressive growth rate and high early strength, which can support the roof in time and effectively control the deformation of surrounding rock. It is applicable to the mining technology of coal pillarless filling body. As a part of green mining, its technology is an advanced technology that can promote mine safety and improve mine mining, and can bring great social and economic benefits to coal mines. Laboratory research shows that the best material ratio suitable for site engineering conditions is: cement: fly ash: coal gangue = 1:2:5, where the mass fraction of mud is 78% and the amount of early strength agent added is 2.0%. The early strength of the backfill specimens with this ratio can reach 2 MPa and the late strength can reach 13.8 MPa. The specimens still have high residual strength and good bearing capacity after compression damage. The test results show that the cement content and mass concentration are the main factors affecting the early strength of backfill materials, the relative content of gangue aggregate mainly affects the late strength of backfill, the early strength agent has a certain effect on the early strength of the material, and the compressive strength decreases with the increase of the mass ratio of gangue cement.

References

[1] YuanLiang. (2017). Scientific conception of precision coal mining. Journal of China Coal Society (01), 1-7. 2016.1661

[2] Xiaomeng Liu and Xiangrui Meng. (2018). Evaluation and empirical research on the energy efficiency of 20 mining cities in Eastern and Central China. International Journal of Mining Science and Technology, 28(3), pp. 525-531.

[3] Xinshuai Shi et al. "Stability Control of Gob-Side Entry Retaining in Fully Mechanized Caving Face Based on a Compatible Deformation Model". Computer Modeling in Engineering & Sciences 124. 1(2020): 315-343.

[4] Deyu Qian et al. "Stability of goaf-side entry driving in 800-m-deep island longwall coal face in underground coal mine". Arabian Journal of Geosciences 9.1(2016).

[5] Qiang Sun and Jixiong Zhang and Nan Zhou. (2018). Study and discussion of short- strip coal pillar recovery with cemented paste backfill. International Journal of Rock Mechanics and Mining Sciences, 104pp. 147-155.

[6] Pu Shijiang et al. "Determination of Reasonable Width of Filling Body for Gob-Side Entry Retaining in Mining Face with Large Cutting Height". Geofluids 2022(2022)

[7] Weitao Li and Li Weitao and Guo Zhibiao. "Numerical simulation study of the support system by gob-side entry retaining by roof cutting". IOP Conference Series: Earth and Environmental Science 570.

ISSN 2706-655X Vol.5, Issue 1: 48-56, DOI: 10.25236/IJFET.2023.050108

2(2020): 022053-.
[8] Dong Yue et al. (2021). Experimental Study on the Compaction and Deformation of Filling Gangue by Reducing Waste Gangue for Filling Mining. Frontiers in Materials, 8
[9] Chen Denghong et al. "Study on the Optimization of Proportion of Fly Ash-Based Solid Waste Filling Material with Low Cost and High Reliability". Sustainability 14.14(2022): 8530-8530.
[10] Qiang Sun et al. (2020). Backfill mining alternatives and strategies for mitigating shallow coal mining hazards in the western mining area of China. Quarterly Journal of Engineering Geology and Hydrogeology, 53(2), pp. 217-226.
[11] Jixiong Zhang et al. (2016). Green coal mining technique integrating mining-dressing-gas draining-backfilling-mining. International Journal of Mining Science and Technology, 27(1), pp. 17-27.
[12] Jixiong Zhang et al. (2016). Research and application of roadway backfill coal mining technology in western coal mining area. Arabian Journal of Geosciences, 9(10).