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Application of Long-Distance Pre-Grouting Technology in a Coal Mining Face with Large Cutting Height

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Abstract

Coal face with large cutting height is popular in the coal mining industry because of dramatic productivity and efficiency. The coal wall slab problem of the coal wall slab problem of the large mining face seriously hindered the efficient and safe production of the mine. To solve this problem, a long-distance pre-grouting material and a new double-liquid borehole sealing material were proposed, and based on the research on the performance of grouting material, the ratio optimization was carried out. In addition, the related long-distance pre-grouting technology including drilling arrangement and sealing was proposed. Results indicate that final proportions for the long-distance grouting material among superfine Portland cement, composite retarder, composite early-strength admixture, and water cement ratio are 100%, 2%, 2%, and 0.6:1, respectively. For the double-liquid borehole sealing materials, the mixing amounts of the composite retarder A and composite retarder B are 0.5% –1.0% and 1%, respectively, and the water cement ratio is 1:1. And the industrial experiments show that the stability of the coal wall is significantly improved, and good economic benefits is achieved. This study provides a significantly guidance for the application of long-distance pre-grouting technology in coal mining face with large cutting height practical engineering.

Keywords: Long distance, Grouting, Coal mining, Large cutting height, Reinforcement, Mining engineering

1. Introduction

Coal resource in China is abundant, especially for coal fields located in provinces, such as Shaanxi, Shanxi, Inner Mongolia, and Sinkiang. Some of these provinces have great potential to build coal mines with an annual production surpassing ten million tons [1]. Subject to the characteristics of coal seam mechanics, lithology of the top and bottom floors, such coal seams are very suitable for fully-mechanized mining technology [2]. For example, in 2009, the world's first 7-meter high mining fully-mechanized mining face was successfully put into use at 22303 working face of Bulianta Coal Mine. In 2017, the world's first 8-meter high mining fully-mechanized mining face equipment was working in 12511 of Bulianta Coal Mine. In 2018, the world's first set of 8.8-meter of super-large mining height fully-mechanized mining intelligent equipment was put into use in Shendong ordos Shangwan coal mine, which was also the current world displacement of a working face with 8.8-meter of fully-mechanized mining height, was a "super project" of the coal industry.

With the improvement of the comprehensive mechanization degree and management level of coal mines in China, the fully-mechanized top coal caving technology has gradually matured and has become one of the main mining methods for thick and extra-thick coal seams in China [3, 4]. However, the main problem restricting its safety and mining in colleges and universities is the poor stability of coal wall. It has always been a research hotspot in fully-mechanized caving mining. Generally speaking, the use of large resistance brackets, improved initial support of the bracket, accelerated advancement of the working surface, rational design of mining height, scientific use of the front beam and expansion methods such as beams can alleviate the stress concentration on the inner wall of coal walls [5]. These schemes do not actively improve the internal stress of the coal body. By grouting, the strength of the coal body that has been broken or has a tendency to break can be imparted from the inside, thereby improving its bearing capacity under stress disturbance.

The stability of coal wall is a problem that must be faced and solved scientifically in fully mechanized mining face with large mining height. Although the previous studies on the stability of coal body or coal pillar involve more [6-10], the research on the stability of coal wall in fully mechanized mining face with large mining height has certain limitations, and more detailed research work needs to be carried out urgently. On the problem of coal wall grouting in fully mechanized mining face with large mining height, there have been corresponding research results on the reinforcement of coal wall grouting at present, but the grouting distance is relatively short, which is mostly confined to a certain extent (less than 50 m) deep in the coal wall. Therefore, for the safe exploitation, it is of great significance to ensure the stability of coal mining face with large cutting height.

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2. State of the art

As one of the methods for maintaining the stability of coal wall on the working surface, the scholars all over the world have carried out a lot of research on it. Yang Sheng-li et al. [11] showed that the coal wall slab can be effectively prevented by reducing the mining height improving the support strength and using the coal wall grouting reinforcement. Meanwhile, they studied the reasonable grouting pore size of the grouting and strengthening coal wall by UDEC numerical simulation. Zhan Jin-wu et al [12] prepared grouting stone samples by simplifying the control of grouting simulation process, and carried out research on the dynamic characteristics of grouted mudstone under different grouting content ratios and water-bearing conditions. The test results show that the change of grouting content ratio has a great influence on the dynamic mechanical properties of the sample. Only when the mudstone is moderately broken and the slurry has good injection conditions, the grouting effect can be optimized. Under the same content ratio condition, the change of water content also has a great influence on the dynamic mechanical properties of the sample. The higher the moisture content of the sample, the smaller the peak strength and elastic modulus are generally. Feng li-min et al. [13] pointed out that the difference of abutment pressure is the root cause of the severe deformation of narrow coal pillar, and believed that the grouting cement can improve the coal pillar's self-supporting capacity and reduce the pressure difference between upper and lower sides. Based on the spherical expansion theory model, reasonable parameters of grouting hole spacing and grouting pressure are determined. Fang ming-xing [14] proposed the dual-liquid sulfoaluminate cement-based grouting material for mine, and studied the influence of such factors as the composition and particle size of the material on the stability of chemical shrinkage volume and hydration heat. Through practical engineering application, it is shown that this material is an excellent grouting material with good grouting effect. Based on the Newtonian fluid rheological equation and the seepage motion equation, Yang Zhi-quan et al. [15] studied the theoretical calculation formula of the partial diffusion radius of the hemisphere in the Newtonian fluid column-hemispherical penetrating grouting form and the partial diffusion height of the cylinder. The effects of Newtonian fluid rheology, grouting pressure, ground water pressure and water temperature of the configured fluid on the partial diffusion radius of the hemisphere in the Newtonian fluid column-hemispherical penetrating grouting form and the partial diffusion height of the column were analyzed, and the grouting test was designed to verify it.

At present, grouting materials are mainly divided into cement based grouting materials, chemical grouting materials and organic-inorganic composite grouting materials. Due to the different requirements of grouting materials for fractured rock mass under different geological conditions, a large number of targeted grouting materials have been developed [16,17]. Zhang et al. [18] prepared a novel double liquid grouting material (ultra-fine sulfoaluminate cement-based grouting material). To solve the issues that grouting materials easily run out before it solidified, Zhang et al. [19] developed a new type of cement paste, namely SJP grout (S-Sichuan, JP-Jinping), which is made up of cement and SJP additives. Kim et al. [20] developed four types of grouts to evaluate the effect of grouting of saturated riprap layers on ground water flow. Li et al. [21] presented the preparation of super early strength grouts. A ternary complex system of sulphoaluminate cement, aluminate cement and gypsum were used in the grouts combined with a variety of additives. Song et al. [22] developed a series of High Performance & Multi-Functional Agent grout materials for an underwater condition. Zhang et al. [23] developed a pasty clay-cement grouting material for soft and lose ground under groundwater conditions.

Based on the specific mine conditions, these studies improve the grouting technology and the grouting method. However, each mine has its own specific conditions, and the results of the above-mentioned research are not of promotional significance. Meanwhile, the above studies do not systematically combine material research with practical application. Therefore, this study endeavored to develop new grouts based on existing materials in laboratory, and then the implementation of grouting boreholes was proposed and optimized. All technical processes should be adjusted accordingly given that the cutting height of coal face was relatively large and the length for both entries was very long. First, the optimization on long-distance grouting material was carried out. Second, a borehole sealing material was proposed to satisfy the requirement of long-distance grouting in soft coal/rock mass. Finally, an engineering field application was conducted to test the results.

The remainder of this study is organized as follows. Section 2 gives the relevant background, including a statement of the pressure distribution around cutting face and Pre-grouting mechanism. Section 3 presents the proposed grouting material and double liquid borehole sealing material in detail. Section 4 describes the engineering application of the materials with the Long-distance pre-grouting technology, and finally, the conclusions are summarized in Section 5.

3. Experimental test on grouting material

Cement-based grouting material has a wide application scope in coal mine reinforcement area. However, this material requires further studies to accommodate long-distance grouting trial in field. Generally, the material should have several peculiarities, such as superfine particle size to enhance reaction speed and permeability, feasible fluidity to guarantee long-distance pipelining, early setting property, and rapid increase of strength and required bonding capacity with cracked rock mass. To satisfy these peculiarities, a series of experimental trials was conducted to optimize the target products.

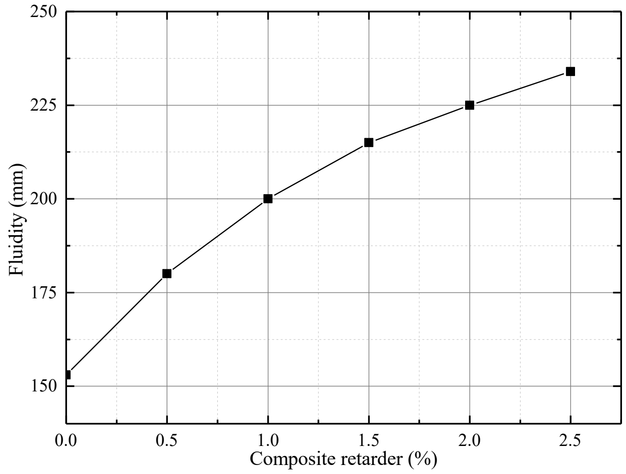
3.1 Optimization on long-distance grouting material

Portland cement is a base material for grouting, but the property can conflict with the requirements of early setting and high early strength. Hence, composite retarder and composite early-strength admixture were proposed, and relevant impacts were investigated.

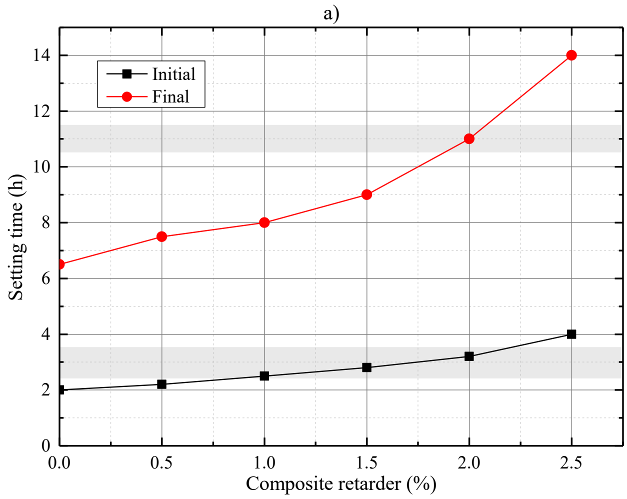
(1) Determination of suitable composite retarder percentage

The Composite retarder greatly affects fluidity and setting time of cement. However, its impacts on strength can be neglected. The results obtained from the fluidity apparatus of cement mortar are shown in Fig. 1(b). The fluidity generally expressed an ascending trend as the percentage of composite retarder increased, but a convex process indicated a slowdown of the increasing speed. In addition, the bleeding phenomenon occurred as the percentage reached 2.5%.

The impacts of composite retarder on the setting time of grouting also deserve attention. The testing results are presented in Fig. 1(b). The figure shows that the initial and final setting time exhibits increased property as composite retarder percentage increased. Higher composite retarder percentage has more prominent effects on final setting time. In actual application, the initial and the final setting time should be nearly 3 h and 11 h, respectively. The alternative data dropping in the scope define the suitable composite retarder percentage as 2%, as observed in the shaded areas in Fig. 1(b).



a)

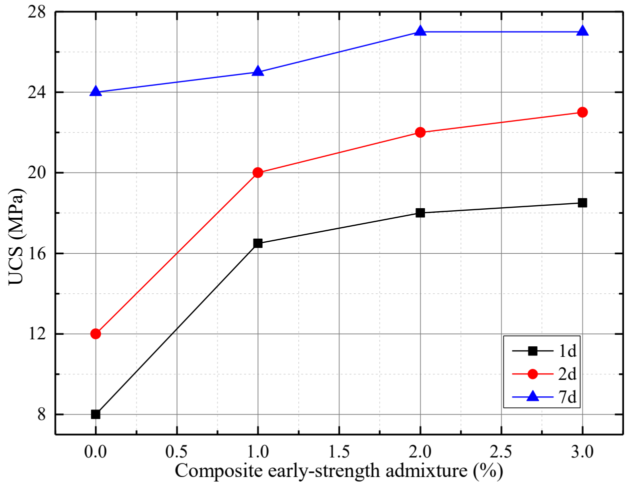


b)

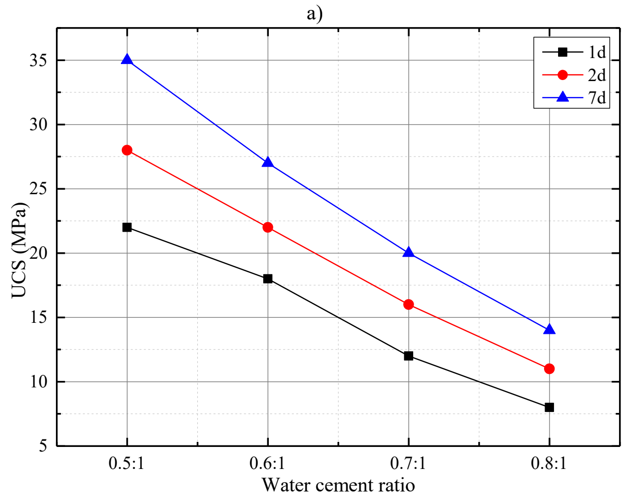
Fig. 1. (a) Relationship for composite retarder percentage vs. fluidity, and (b) relationship for composite retarder percentage vs. setting time

(2) Determination of percentage of composite early-strength admixture

Different from the properties of composite retarder, the percentage of composite early-strength admixture should have noteworthy impacts on strength, but its impacts on fluidity and setting time are unapparent. Fig. 2(a) shows the relationship between percentage of composite early-strength admixture and uniaxial compression strength (UCS) under different curing times. Evidently, the addition of compression early-strength admixture was a motivating factor for increasing the UCS of the specimens. However, this enhancing effect became insignificant as the percentage surpassed 2%. Setting the percentage of composite early-strength admixture to 2% is cost effective and result conspicuous.



a)



b)

Fig. 2. (a) Relationship between percentage of composite early-strength admixture and UCS under different curing times, and (b) Water cement ratio vs. UCS under different curing time

(3) Determination of appropriate water cement ratio

Water cement ratio has huge impacts on the bearing capacity of grouting material. The UCS under different ratios for different curing times was investigated, as shown in Fig. 2(b). Evidently, UCS dropped dramatically as water cement ratio increased. However, selecting relatively low ratio was unscientific because it could cause operational difficulties and increase material cost. Hence, a water cement ratio of 0.6:1 was defined.

The final proportion among superfine Portland cement, composite retarder, composite early-strength admixture, and water cement ratio was 100%, 2%, 2%, and 0.6:1, respectively. The prepared grout was a type of inorganic material characterized by superiorities, such as dry powdery, non-toxicity, and non-corrosiveness. When mixed with water based on water cement ratio of 0.6:1, the fluidity could be feasibly maintained during the first 30–40 min. Subsequently, it would gradually turn thick and completely lose its fluidity in 2–3 h. The solidification occurred after approximately 10 h with rapid increase in strength. The test results indicated that the UCS could reach up to 19 MPa after one day, 28 MPa after three days, and 32 MPa after seven days.

3.2 Double liquid borehole sealing material

In engineering practice, the excavation of peripheral rock mass belongs to fractured zone, and cracks and weak planes are abundantly distributed in the inner section. Long-distance grouting requires certain fluidity of the grouting. A favorable fluidity in an hour should be guaranteed to satisfy the long-distance transmission and diffusion. A specific grouting pressure should also be considered; otherwise, the possibility that the grout cannot arrive at the deep zone inner coal/rock mass is great. These factors, however, are disadvantageous to the stability of the coal/rock mass in fractured zone. As a result, grout leakage or coal/rock burst and fall should occur. To solve this problem, a borehole sealing material must be proposed, and it should have properties that can satisfy the requirement of long-distance grouting in soft coal/rock mass.

Different from existing double-liquid borehole sealing materials utilized in coal mine grouting areas, the materials applied here should have several peculiarities listed as follows:

1) Influence sphere. The influence sphere of the existing material was generally less than 20 m. This range should be increased to 30–40 m in long-distance grouting technology.

2) Utilizing occasion. In long-distance grouting, a delayed coagulation property was required because the material should have two utilizing occasions. First, utilizing the sealing material when the borehole was drilled at an approximate depth of 30 – 40 m would facilitate a formation of a reinforced area avoiding possible leakage during subsequent deep-hole grouting procedure. Second, it could serve as a cooperative measure to remedy possible leakage during deep-hole grouting procedure.

3) Fluidity. The sealing length of the traditional material was generally less than 20 m, and the fluidity time and the setting time were less than 5 min and 20–30 min, respectively. However, for long-distance grouting, the diffusion scope of the sealing material should be extensive and should have leakage stoppage property. The fluidity time and setting time were 15 min and 40–50 min, respectively.

4) Water cement ratio and strength. The traditional material generally has relatively small water cement ratio and less setting time. The requirements for borehole sealing in long-distance grouting included low water cement ratio to guarantee strength, prolonged fluidity time, and the setting time should be unaffected at the same time.

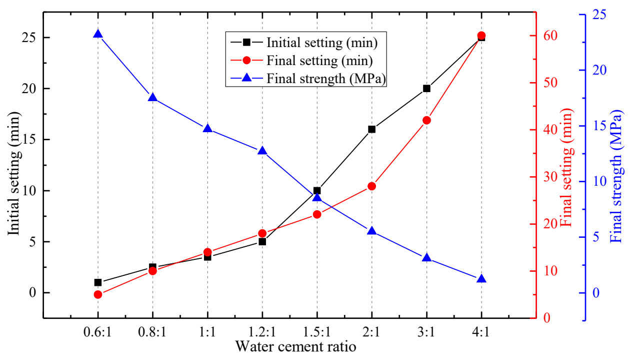


Fig. 3. Setting time and strength alterations with respect to changes of water cement ratio

A certain additive was added to prepare a double-liquid borehole sealing material on the basis of existing material. The main difference of the traditional material was its delayed coagulation property. Some mechanical properties of the traditional material were tested, as shown in Fig. 3. These parameters were critical for preparing new products because all alterations were based on the traditional material. The figure indicated that the final strength expressed a descending trend as water cement ratio increased, whereas the initial setting time and final setting time exhibited ascending trend under the same precondition. For the properties of the target product, water cement ratio should be not higher than 1:1; thus, the final strength could be ensured. The time to lose fluidity (initial setting time) and the hardening time (final setting time) were accordingly adjusted to satisfy engineering requirements.

The raw materials were sulphoaluminate cement clinker, anhydrite, composite retarder A and composite retarder B. Retarder A mainly functioned on sulphoaluminate cement clinker whereas retarder B mainly functioned on anhydrite. The mixing percentage for retarder A ranged from 0% to 1.5%, and the mixing percentage for retarder B ranged from 0% to 2%, the water cement ratio remained constant at 1:1. Under the prerequisite, the different percentages of retarder A and B would bring about different results. The test resuplts are listed in Table 1.

Table 1. Variation of initial setting time and final setting time under different percentages of retarder A and B

Retarder A / Retarder B	0.0 %	0.5 %	1.0 %	1.5 %
0.0 %	45/90*	48/100	52/108	60/120
0.5 %	25/65	26/68	28/70	32/74
1.0 %	7/40	10/42	15/45	20/52
1.5 %	4/18	6/21	7/24	9/28
2.0 %	2/13	2.5/13	3/13.5	3.5/14

* The number before the slash is the initial setting time (min), and the number after the slash is the final setting (min).

These regulations indicate that the initial setting time should be at 15 minutes and the final setting time should be at 40–50 minutes. Items in Table 1 caught our attention. Hence, the basic proportion for the double-liquid borehole sealing material was as follows: the mixing amounts for composite retarder A and composite retarder B were 0.5%–1.0% and 1%, respectively, and the water cement ratio was 1:1.

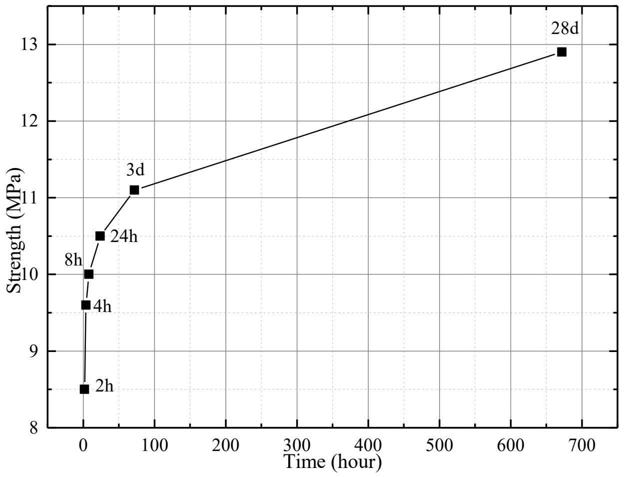


Fig. 4. Strength vs. curing time of the prepared double-liquid borehole sealing material

Under the circumstance, the sealing occasions could be guaranteed. The strength test result is shown in Fig. 4. The curve recorded a two-hour strength of 8.5 MPa and a long-term strength of 12.9 MPa. The parameters dropped in the safety data scope of shallow borehole sealing and emergency handling during grouting leakage occasion. Thus, the engineering requirements could be addressed.

4. Engineering application

4.1 Geological conditions

The geological setting of Zhaozhuang coal mine was comparatively complex. The thickness of coal seam could range from 3.5 m to 6.2 m with an average value of 5.5 m. The inclination of the coal seam also ranged from 1° to 15° with an average value of 8°. The burial depth of coal seam ranged from 463.9 m to 633.9 m with an average value of 500 m. Under the circumstance, the mining method utilized was fully mechanized mining with large cutting height. However, geological conditions upper or beneath the coal seam were extremely complex, causing many technical difficulties, such as threatened safety and delayed normal production. Generally, the coal seam expressed a relatively low strength and could be crushed by hand, and the immediate roof overlaying the coal seam belonged to the fracture-prone mudstone. The full-seam mining method adopted here was very likely to cause rib failure or small-scale roof fall. The situation worsened because of the large height bringing gap or low supporting force between the roof and hydraulic supports.

Although many measures have been used to solve the problems, the outcome was unsatisfactory. An example is grouting reinforcement on coal mining face or direct shotcreting on ribs, by which the former caused obstruction to coal mining procedure and safety concerns whereas the latter generally failed in maintaining stability of the ribs. The strength of the coal seam specified by abundantly distributed cracks should be restored. A pre-grouting measure should be adopted to reinvest the strength of coal seam.

4.2 Drilling scheme for long-distance borehole

Drilling a borehole with distance reaching 100 meters is difficult due to the complexity of geology and cracked occurrence of coal body. The pre-shaped boreholes can collapse very easily under a street disturbance of coal cutting face. Problems, such as grout leakage during operation and jamming of a drilling tool, are also almost impossible to avoid. To facilitate the integral grouting process, a graded borehole drilling and segmented grouting technology was proposed, as schematically illustrated in Fig. 5.

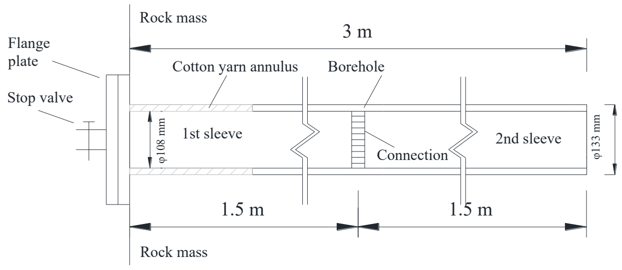


Fig. 5. Schematic sketch for graded borehole drilling and segmented grouting technology

The detailed procedure for this technology includes the following steps. A three-meter-long borehole was drilled by a φ133 mm bore bit. Then, a three-meter-long sleeve connected by two 1.5-meter-long sleeve units was installed, the diameter of which was 108 mm. A flange plate was welded on its external side for grouting, and cotton yarn annulus was swathed on the first sleeve along a range of neighboring borehole collar. Subsequently, the grouting procedure was started. The grout would fill up all space between the borehole and sleeves. Moreover, a certain scope of cracks distributed around the borehole inner coal/rock mass would be bonded and reinforced. After 1 h, the flange plate was dismounted, the drilling procedure was restarted with a φ75 mm bore bit until a preset drilling depth was reached. If unexpected problems, such as borehole collapse or jamming, occurred again, then the flange plate was remounted and the bore bit was retreated. Thus, another round of grouting could be restarted. The borehole drilling and grouting proceeded alternatively until the preset depth was attained using this measure.

4.3 Long-distance borehole sealing technology

Long-distance deep borehole drilling should be executed in advance. When the coal cutting face draws near, the cracks inner the coal/rock mass in front of the working face would adequately develop and the cracked zone would be formed based on mining pressure theory [24, 25]. These cracks created great opportunities for the penetration of grout in the coal/rock mass. Thus, the low-strength coal/mass could be reinforced. During this procedure, the borehole sealing technology was vital, and the sealing would directly determine the grouting effects. A proposed sealing measure is schematically presented in Fig. 6.

As shown in the Fig. 6, the structure comprised by borehole sealing tube, cotton yarn, seamless tube, high-seamless tube. The welded iron wire could fix the position of the cotton yarn along the seamless tube. The borehole sealing tube was utilized for sealing purposes, finally pressure ball valve, and iron wire coiled around the facilitating the formation of a 20-meter-long sealing segment and guaranteeing the compactness of the integral borehole. The total length of the DN20 seamless tube was 20000 mm assembled by ten tube units, the length of each unit was maintained at 2000 mm. A PVC tube with 100 m length and 50 mm diameter was connected to the far right end of the DN20 seamless tube. The PVC tube was used for grout-transmission purpose. The grout spraying holes were arranged at its last far end, and the scope was 20 m in length. In this setup, the sealing procedure was conducted after the completion of borehole drilling or before the actual grouting procedure. On the one hand, the effectiveness was ensured; on the other hand, the borehole wall was supported in case of collapse.

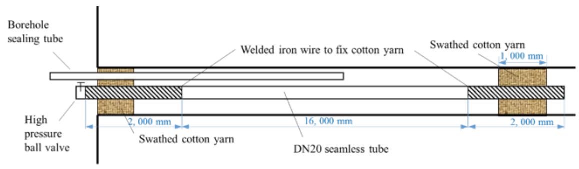


Fig. 6. Schematic sketch for the borehole sealing structure

4.4 Arrangement for grouting boreholes

The testing areas included extremely cracked areas in coal mass and overlaying roof. As shown in Fig. 7, the ellipse-circled sections in the tailentry and headentry represented the borehole arrangement. The total length of each testing segment was 60 meters and the arrangement of these two sections was asymmetric.

As for borehole arrangement in each entry, the details of the 13071 headentry were as follows: two rows of boreholes were arranged, and the diameter and depth of the boreholes were 75 mm and 115 m, respectively. The distribution of the two rows of boreholes showed a staggered pattern. Each row contained six boreholes with interval between neighboring ones maintained at 10 m. The distance from the floor to the upper row was 5.5 m and 2.5 m for the lower row. The horizontal distance between the upper row and the lower row was 5 m, as shown in Fig. 8(b).

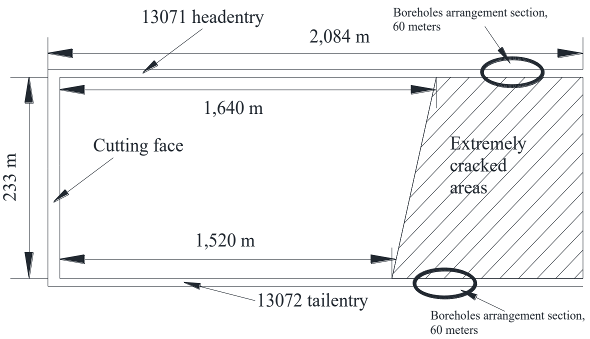


Fig. 7. Borehole arrangement in entries for long-distance grouting purpose

The borehole arrangement pattern in the coal/rock mass also expressed differences between the upper and lower rows. The boreholes in the upper row had an elevation of 2° and 1° for the lower row. Under the circumstance, a certain section of the upper boreholes reached into the overlying roof of coal seam, thereby resulting in a 3 m distance from the top of the borehole to the coal seam. An operation platform with a length of 15 m was arranged in entry to facilitate the construction progress and reduce the labor intensity due to the comparatively large height from the borehole to the floor.

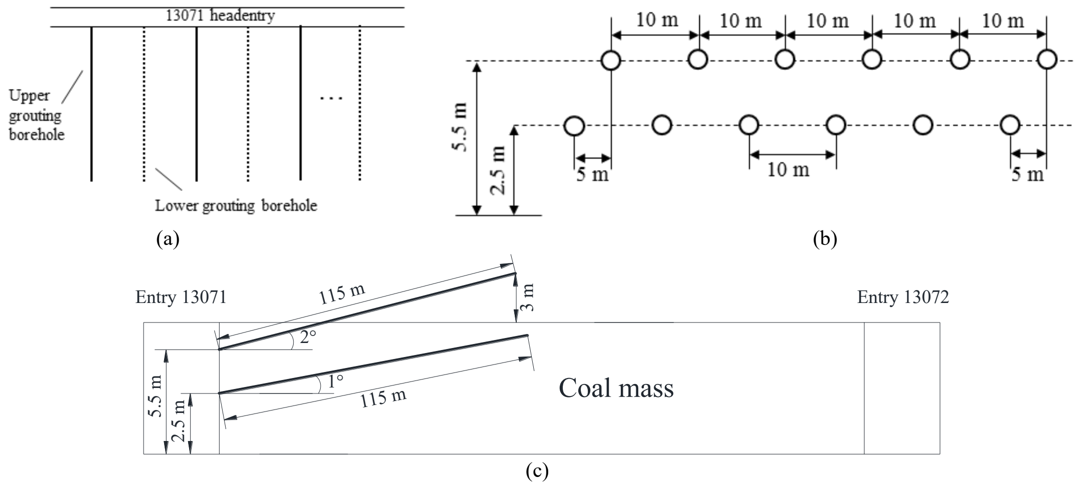


Fig. 8. Distribution pattern for boreholes in 13071 headentry. (a) Top view of the grouting boreholes. (b) Borehole arrangement pattern on the entry wall. (c) Section view of the borehole spanning dimension

The borehole arrangement in entry 13072 was largely similar to that in entry 13071 except for the height differences. The lower and the upper rows of the boreholes were 1 and 3 m to the floor of entry, respectively. The remaining parameters were identical to those of the boreholes in the entry 13072. The total height of 13072 tailentry at 3.5 m caused alternation.

The fluidity, initial setting time, and final setting time of the grouting material had strict requirements due to the large cutting height and long distance of the grouting borehole. A grouting scheme specified by alternative grouting was proposed on the basis of a series of tests conducted in the previous sections. The grouting would switch between double-liquid sealing material and single liquid grouting material; the water–cement ratio of the former was 1:1 and 0.6:1 for the latter. The grouting pressure was a vital parameter that determines the grouting effects. The pressure was not constant during the operation. It generally floated between 24 and 27 MPa. If the surrounding rock mass was extremely cracked or the grouting leakage could be dramatically noticed, then the pressure should be turned down accordingly. The pressure limit of the grouting amount of the single borehole should be reached before grouting is suspended. If abnormal grouting amount and long duration were noticed, potential channels of the inner rock mass for grouting leakage should be considered. The maximum grouting amount of the single borehole could reach up to 15.15 tons based on the data recorded in the field.

4.5 Effects evaluation of the industrial experiment

The stability and compactness of grout-reinforced area should resist the stress disturbance of the coal cutting face. As the cutting face advanced to the extreme crack area, the failure patterns of the ribs in 13071 headentry and 13072 tailentry were investigated. In summary, the rib situation in the grouted segment (ellipse–circled section) was much better than the segment without grouting. Fig. 9(a) and (b) presented a comparison when the coal cutting face first entered the extremely cracked area. The upper end of the cutting face was still in the nongrouted area whereas the lower end only touched the grouted area due to the asymmetric property of the cracked area, as shown in Fig. 7. Fig. 9(a) shows that the collapse of the ribs in the nongrouted segment was evident and even the front guard boards of supports were not able to obstruct the outward burst of coal mass. However, stability of grouted segment exhibited a desired situation, the stability of the rib was under control, and the front guard boards could have good contact with coal mass.

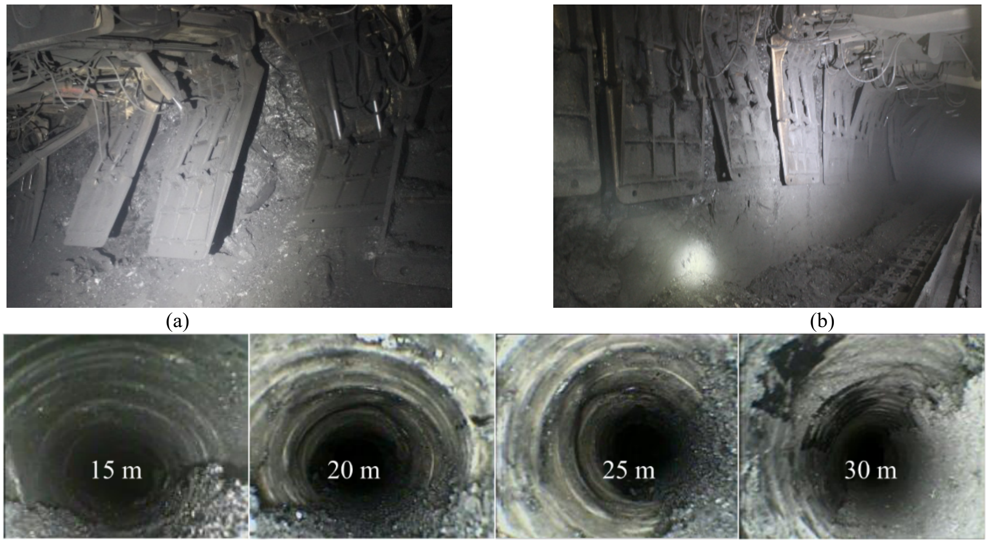


Fig. 9. (a) Photo of the rib in 13071 headentry. (b) Photo of the rib in 13072 headentry. (c) Snapshots from the video captured by borehole imaging

In Fig. 9(c), snapshots from the video captured by the borehole imaging were presented. This method is currently very popular in revealing inner flaws in the boreholes [26]. The imaging boreholes were arranged at the outermost side of the upper (lower) row of the grouting boreholes. The horizontal distance to its neighboring grouting borehole was 3 m. The diameter and depth of the imaging boreholes were 75 mm and 40 m, respectively. The snapshots revealed that the borehole wall was relatively stable, and the cracks were filled up by the grouting material. The pulverulent coal was also cemented together as an integrity. The rare distribution of grout for snapshot at 15 m was mainly because of the sealing effects. Fig. 5 shows that the sealing prevented potential leakage during grouting procedure, and it avoided potential collapse of boreholes. The testification proved that long-distance grouting was able to improve the integrity of the cracked coal mass. It strengthened the ribs and reduced the possibility of deformation or supporting failure.

Advancing the speed of the coal cutting face was a vital factor, which could evaluate whether the coal mass was intact or not. A relatively faster speed could be generally obtained if the coal mass had certain integrity, and the collapse of the surrounding coal mass around the entries could be avoided. Fig. 10 shows the relationship between advancing speed and time. Almost 70-day data monitoring indicated that the advancing speed could mount dramatically if the extremely cracked area had been previously grouted and then reinforced accordingly. The coal cutting face was located in normal area prior to September 27. The strength of the coal mass was largely feasible for normal production requirements. However, after September 27, the coal cutting face was in the extremely cracked area. Nonetheless, the coal mass and overlying roof in front of the cutting face were not reinforced by grouting as the face moved forward during a period from September 27 to October 19. On October 20, the coal cutting face was initially in touch with the grouting area, and the curve recorded an evident increase. The drop on October 29 was caused by the routine safety check procedure.

The average cutting number in each section prior to the arrival of the extremely cracked area (normal area) was 3.1 per day and 4.3 per day in extremely cracked area without grouting. However, the speed was increased to 4.9 per day in the grouting area, which also incorporated the speed during the safety check process on October 29. Otherwise, the effects would have been much more affirmative.

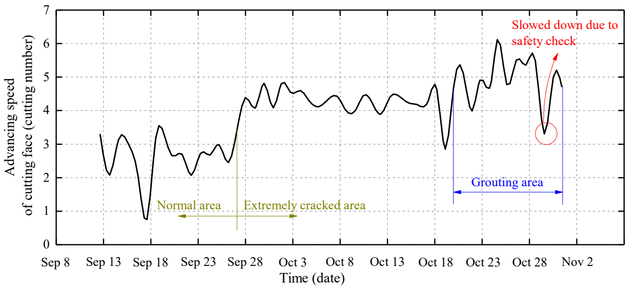


Fig. 10. Relationship between advancing speed of cutting face and time

The small scale of chemical grouting procedure was also carried out on coal cutting face in the case of face collapse considering the large cutting height in the field [27]. Generally, the cutting face with favorable stability required less amount of chemical grout, whereas the cutting face with poor stability required more. The amount of chemical grouting became an evaluator that determines the stability of coal cutting faces. Fig. 11 showed that the recorded variation of the amount of chemical grouting with the time. The average utilized bucket of chemical grouting per day in each section was adopted to assess the effectiveness of the long-distance grouting.

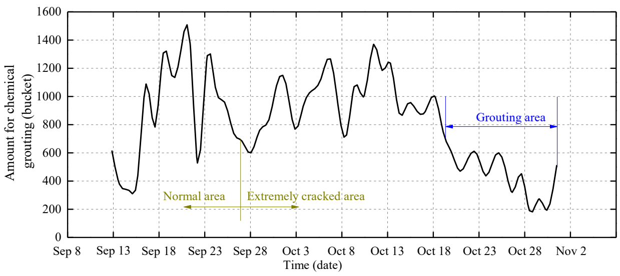


Fig. 11. Relationship between chemical grouting amount and time

Maximum bucket utilized per day in the normal area could surpass 1400, and average bucket was 892. The average daily utilized bucket in the extremely cracked area without long-distance grouting was 991.7. It decreased to 443 buckets in the grouting area with a maximum of 616 buckets and minimum of 190 buckets.

The results herein proved that the long-distance pre-grouting process in front of the coal cutting face had a noteworthy impact on improving the mechanical properties of coal mass and its overlying rock mass. It maintained the stability of coal ribs and avoided potential collapse. The chemical grouting amount utilized on the coal cutting face was reduced. Moreover, the advancing speed of coal cutting face was largely improved, evidently improving coal production.

5. Conclusions

To solve the problem of coal wall stability in fully mechanized face with large mining height under complex geological conditions, a long-distance grouting scheme was proposed, and developed a long-distance pre-grouting material and double liquid borehole sealing material. The ratio optimization experiment of this material was carried out, and conducted industrial experiments. The following conclusions were obtained.

(1) The final proportions of grouting materials among superfine Portland cement, composite retarder, composite early-strength admixture, and water cement ratio were 100%, 2%, 2%, and 0.6:1, respectively.

(2) The basic proportion of the double-liquid borehole sealing material was also defined, the mixing amounts of the composite retarder A and composite retarder B were 0.5%–1.0% and 1%, respectively, and the water cement ratio was 1:1.

(3) Industrial tests have shown that the problem of coal wall slabs in large mining height working face has been effectively solved and the economic benefits are good.

The diffusion process of grouting material in coal body is not only related to its own performance (fluidity, setting time and strength), but also to the cracks in coal body. Therefore, the seepage law of grouting material in cracks needs further study.

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