Application of Inorganic Solidified Foam to Control the Coexistence of Unusual Methane Emission and Spontaneous Combustion of Coal in the Luwa Coal Mine, China

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Abstract: Unusual methane emission and spontaneous combustion of coal induced by the air leakage are both hazards during mining. The most common practice has been to improve mine safety is sealing the mining fractures. In this paper, the methane and geology, coal spontaneous combustion characteristics and the coexistence of methane emission and spontaneous combustion of coal were analyzed. The preparation system of inorganic solidified foam (ISF) in field applications is studied and the working principle of generating device consists of foam generator and mixer was expounded. The technical plan of site construction is that the foam fluids was injected to respectively seal the mining fractures behind hydraulic supports, the cavities of air return corner, and the fractures nearby the coal pillar. After the foam fluids injection, the two stress values in the coal pillar eventually maintained above 15.5Mpa and 13Mpa, respectively. It indicated that the ISF can enhance the bearing stress ability of the coal pillar by transforming the stress state from two dimensional to three dimensional. The methane concentration in the air return corner and air return roadway declined significantly to 0.63% and 0.25%. The differential pressure inside and outside of the 4301(1) goaf fluctuated between -100pa to 150pa and the concentration of CO and O_2 declined to 9ppm and 6%. The CO concentration in the air return corner finally reached a stable level of 6ppm. What that all means, the foam fluids can seal the air leakage and inhibit spontaneous combustion of coal effectively.

Keywords: Methane emission· Spontaneous combustion of coal· Sealing the air leakage· Mining fractures· Inorganic solidified foam

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1 Introduction

Methane associated with coal seams are formed as a result of the coalification process.[1] The methane found in coal seams poses a hazard when encountered in sufficient quantities in the coal seam. Large amounts of methane are released in the mine working faces gradually as mining progresses.[2] Since methane in mines can cause a variety of problems ranging from asphyxiation (the concentrations of carbon dioxide above 1-2% in air have a major detrimental physiological effects) and burning to violent explosions (explosive range of 5-15%),[3-5] the maximum allowable concentration of methane in the atmosphere in China coal mines is 1%.[6] The methane explosion in the Sun Jiawan coal mine was caused by abnormal methane emission and aggregation in the 3316 air return roadway.[7] On the other hand, atmospheric methane is the second most important greenhouse gas next to carbon dioxide, accounting for >15% of the global warming.[8, 9] The methane emission sources can be divided into coal wall ahead of the working face, goaf behind the working face, the nearby goaf, and the lower slicing coal seam. All of these sources apply methane by the fractured channels induced by coal mining. Although extensive research has been carried out to control unusual methane emissions in coal mines, the common practice has been to improve mine safety by sealing the mining fractures.

According to the COCT (coal-oxygen complex theory), oxygen plays a vital role in igniting spontaneous combustion.[10-12] The spontaneous combustion of coal is due to the heat produced by the exothermic reaction between coal and oxygen permeating through the mining fractures.[13, 14] Any fire requires three elements to propagate: fuel, oxygen, and a source of heat. If any one of the three sides of the fire triangle is removed, a fire cannot continue to burn. Oxygen removal depends on either the introduction of an inert gas or the isolation of the fire zone from sources of fresh air. If the air leakage can be sealed, the fire may eventually be extinguished after a long time.

So when the unusual methane emission and spontaneous combustion of coal coexist, the fracture filling and sealing is the effective prevention measure. The existing mining fracture sealing materials can be divided into two categories of inorganic and organic. The inorganic materials include fly ash, colloid mud, composite coating materials, etc.[15-17] The organic materials mainly contain polymer gel, foam gel, polyurethane foam, etc.[18-20] They play an active role in the process of sealing air leakage; however, some shortages still exist: such as fly ash, the fly ash slurry only flows along the low-lying fracture channels and it cannot uniformly permeate into the mining fractures in higher places; colloid mud, it accompanies the shortages of poor liquidity, difficult to convey for long distance; composite coating materials, it is only applicable to spray surface fractures; polymer gel, it owns a poor water retention and is easy to dry; foam gel, it is unable to bear the mining stress; polyurethane foam, the heat production of the polymerization reaction is great and may break down to release cyanide at a high temperature. In order to overcome the deficiency of the existing technology of mining fractures filling and sealing, inorganic solidified foam (ISF) was prepared. [21] The fresh state of ISF (foam fluid) can accumulate to high positon, cover and cool high temperature mining fractures. Simultaneously, it owns good heat insulation ability, thermal stability, and adjustable coagulation time. When it is solidified, the ISF can undertake the mining stress and effectively control the secondary deformation of the coal and rock for filling the fracture channel a long time.

In this study, the methane and geology, coal spontaneous combustion characteristics and the coexistence of methane emission and spontaneous combustion of coal were analyzed. Then the preparation system of ISF in field applications and the technical plan of site construction were studied. Finally, In order to better reflect the mainly application effect, the following aspects such as the fracture filling and reinforcing, air leakage sealing, and index gases of coal spontaneous combustion inhibiting were investigated.

2 Background of the study area in the coal mine

2.1 Methane and geology

The Luwa coal mine was located in the town of Zhanghuang, Yutai County, Shandong province. Its verification of production capacity is 1.2 million t/a. At present, the main mining coal seam is 3# with the average thickness of 9.14 m. The roof of the 3# coal seam is mainly composed of mudstone and sandstone, and the floor is mudstone. According to the three dimensional geophysical exploration and the actual exposing situation when mining roadway, five faults with the gap more than 3 m would be revealed during the period of mining the 4301(1) working face. Of which, the gap of the faults named DF79, DF54 and DF57 belong to 4-6.3m, so it has a significant influence on mining of the working face. The sealing property of faults is good, which result in that the methane flow and discharge condition is poor. Due to the stress rupture in the fault formation process, the associated structure of the faults is broken with abundant micro pores, joints and cracks. This provides the space for methane occurrence and contributes to rich concentrated zone of methane. [22, 23] Once affected by mining and blasting vibration, the methane will quickly move to the outside, release and form abnormal methane emission districts. In order to more effectively carry out methane prevention and control, it is necessary to determine the parameters of methane in methane enrichment area and forecast the methane emission in the process of mining. The results are shown in Table 1 and Table 2.

Table 1 The methane basic parameter of 3# coal seam

Apparent density r (t/m^3)	Porosity π (%)	Absolute methane pressure P (Mpa)	Adsorption constant		Proximate analysis			Content of methane W(m^3/t)
			a	b	Mad	Aad	V_{daf}	
1.2653	7.3521	0.59	18.5336	1.0641	1.27	12.92	38.61	5.64

Table 2 The methane emission prediction of the 4303 (1) working face during mining period

Coal production every day（t/d）	Content of methane（m^3/t）	Prediction yield			
		Mining layer (m^3/t)	Lower slicing (m^3/t)	Total	
				(m^3/t)	(m^3/min)
2080	5.64	4.34	4.21	8.56	12.36

2.2 Coal spontaneous combustion characteristics

The coal sample was collected from the 3# coal seam, and the tendency of coal to spontaneous combustion was analyzed according to the "method for identifying tendency of coal to spontaneous combustion by oxygen absorption with chromatograph" (GB/T 20104-2006), the results were shown in Table 3. The dry ash-free volatile of coal sample (V_{daf}) was 37.33%, which is higher than the critical value of 18%. In this premise, the oxygen uptake amount (V_d) was 0.6 cm^3/g, which falls within the scope of 0.4-0.7 cm^3/g, so the classification level is II and the tendency is spontaneous combustion.

Table 3 The analysis results of the tendency of coal to spontaneous combustion

Mad (%)	Aad (%)	V_{daf} (%)	S_Q (%)	True relative density (g/cm^3)	Oxygen uptake amount(cm^3/g)	Classification level	Tendency
1.22	13.05	37.33	1.05	1.40	0.6	II	Spontaneous combustion

The gases which generated in the process of coal oxidation, and can be used to forecast coal spontaneous combustion called index gases. [24, 25] A variety of gases would generate in the coal pyrolysis process. The lowest temperatures of generating them, the relationship between the coal temperature and gas generation quantity varies from coal quality to coal quality. [26] Therefore, selecting the suitable index gases through test can provide the prerequisite for early forecasting the spontaneous combustion of coal. The analyses of gases generation of 3# coal seam sample under programmed temperature were conducted using comprehensive tester of coal spontaneous combustion characteristics, and the results are shown in Fig. 1 and Fig. 2.

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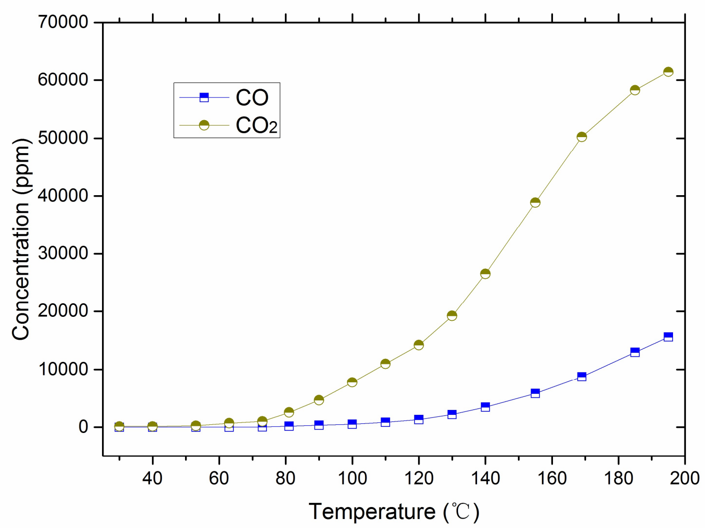

Fig. 1 The changes trend charts of CO and CO_2

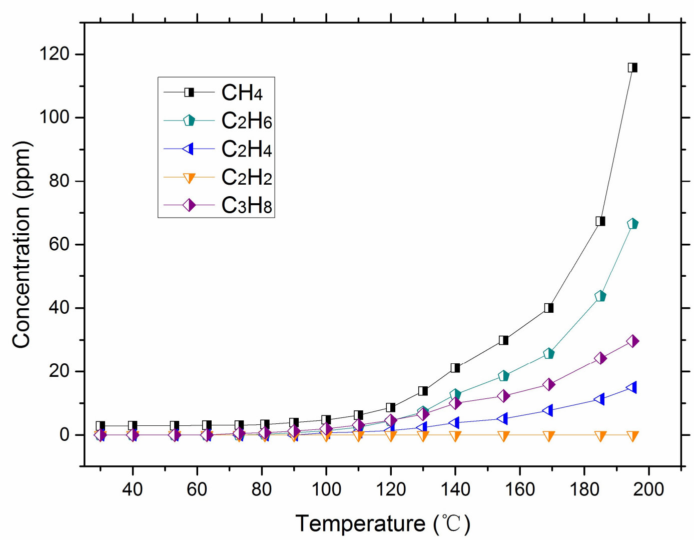

Fig. 2 The changes trend charts of CH_4, C_2H_6, C_2H_4, C_2H_2 and C_3H_8

From the Fig. 4 and Fig. 5, the gas such as CO, CO_2, CH_4 and C_2H_6, C_3H_8 and C_2H_4 have gradually emerged from the coal sample in the oxidation process with the temperature range of 30℃ to 200℃, and most of the gases generation amount exponentially aggrandized with the coal temperature rising, however, the C_2H_2 did not generate in the temperature range. The gas such as CO, CO_2 and CH_4 emerged at 30℃. The CO generation was smaller in oxidation stage with low temperature, and its generation increase rapidly when the coal temperature is over 70 ℃. This shows that coal oxidation has started quickly at this temperature, the physical adsorption is getting more and more weak, meanwhile, the chemical adsorption and chemical reaction has a major position. There is a small

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amount of C_3H_8 at 70℃ and the methane C_2H_6 emerged at 80 ℃. At the latest, the C_2H_4 appeared at 100℃ and then presented a regular changes. The C_2H_2 did not appear in the whole test process, so the generation temperature was higher than 200℃. Once the C_2H_2 generates, it suggests that the coal has happened violent chemical reaction. In conclusion, the gas CO should be taken as an indicator for forecasting, and supplemented by C_2H_4 and C_2H_2 for controlling coal spontaneous combustion.

2.3 The coexistence of methane emission and spontaneous combustion of coal

The 4301 (1) working face and 4303 (1) working face are the first two working faces of the 4# mining area. Among them, the 4301 (1) working face has finished mining, closed and formed the goaf in January 2012. After monitoring and analyzing the methane component and concentration, the results can be obtained as follows: (1) the methane concentration was 70%; (2) the oxygen concentration was 8%; (3) the carbon monoxide concentration was 25ppm; (4) the ethane in the goaf has been unusual several times with the concentration as high as 1000ppm. The differential pressure inside and outside of the goaf was generally between +500 to -400. But when the advancing the air return roadway of the 4303(1) working face, the differential pressure inside and outside of nearby 4301(1) goaf decreased obviously with the value of -40~+60. This is because that the 5 meters wide coal pillar between the two working faces has been crushed by the stress concentration. Even if the coal pillar has been supported by the bolt-mesh-shot concreting, there are still a lot of cracks for air leakage. As shown in Fig. 3, when mining the 4303(1) working face, the narrow coal pillar would be further crushed by the mining stress. By the combination difference of mine pressure and wind pressure at the same time, there is air leakage between 4303 (1) working face, 4303 (1) goaf and 4301 (1) goaf. The methane with high concentration in 4301(1) goaf would flock to the 4303(1) working face and goaf, meanwhile, the fresh air leakage from the 4303(1) working face provides enough oxygen for oxidation of the float coal in the 4301(1) goaf. So the compound hazards of methane and coal spontaneous combustion is likely to form in the region. Moreover, according to the different-source prediction of methane emission in Table 2, the methane yield from lower slicing coal seam is 4.21 m^3/t, accounting for about 50% of the total prediction yield of methane emission during the period of mining the 4303(1) working face. The methane of the lower slicing coal seam would release increasingly influenced by the pressure relief of the overlying coal seam mining. The methane source distribution of the 4303(1) working face can be analyzed in the Fig. 4. In order to effectively dilute the methane concentration, it is necessary to increase air volume. But there will be more air leakage brought into the goaf and the methane

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concentration in air return corner will easily exceed the limit, even the methane explosion will occur. So it is necessary to seal the mining fractures behind hydraulic supports, the cavities of air return corner and intake airflow corner, and the fractures nearby the coal pillar.

Fig. 3 The narrow coal pillar crushed by the mining stress

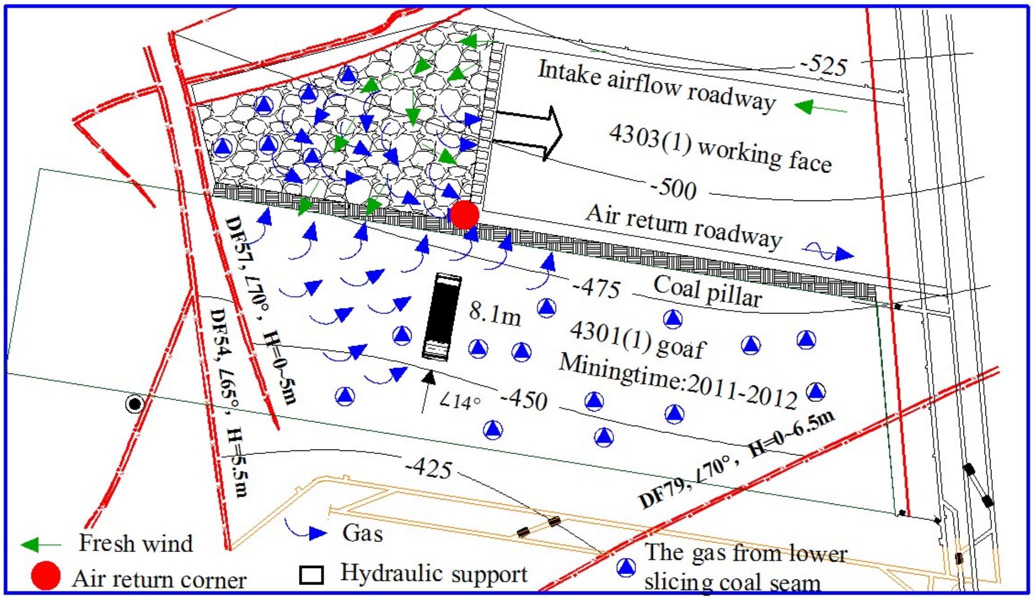

Fig. 4 The methane source distribution of the 4303(1) working face

3 The application process and technical parameters of inorganic solidified foam

3.1 Raw materials

The raw materials in field application process are listed as follows: 325 # ordinary Portland cement, its test and analysis results of X-ray diffraction is showed in Fig. 5; Fly ash (Thermal power plant, Jinwei coal and electricity company), its test and analysis results of X-ray diffraction is showed in Fig. 6; the foaming agent is compounded of 2.5wt.% Lauryl sodium sulfate (SDS) and 2wt.% lauryl alcohol (LA);

Accelerator: the raw materials for preparing the accelerator included coal gangue, fly ash, limestone, and fluorite. The concrete chemical reactions were as equation (1) and (2). The chemical composition of the accelerator is shown in Table 4.

$$C_3AH_6 + CaF_2 \xrightarrow{850-1000℃} C_{11}A_7CaF_2 + CaO + H \tag{1}$$

$$Al_2O_3 + CaO + CaF_2 \rightarrow C_{11}A_7CaF_2 \tag{2}$$

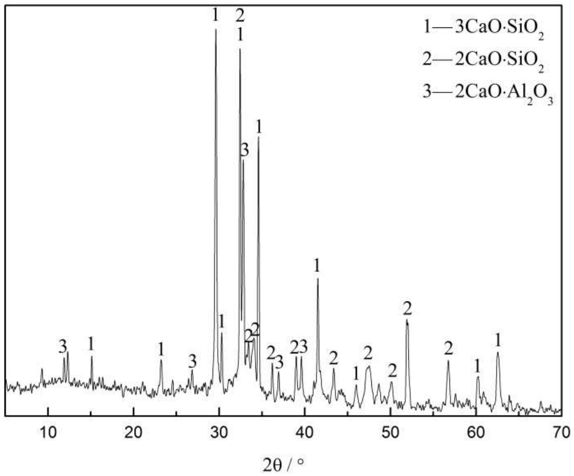

Fig. 5 The X-ray diffraction diagram of the cement sample

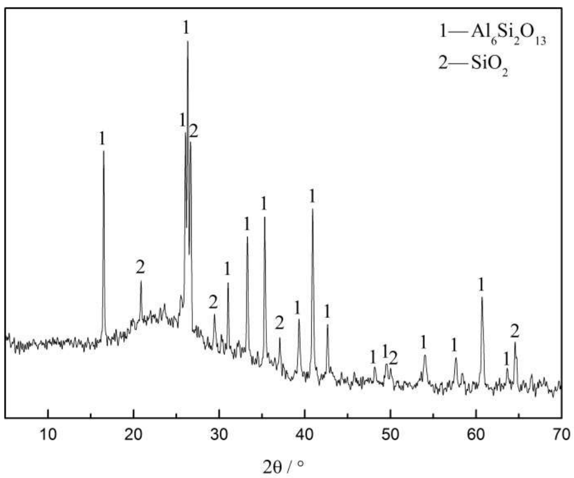

Fig. 6 The X-ray diffraction diagram of the fly ash sample

Table 4 Chemical components of the setting accelerator

Chemical components	Na_2CO_3	$11CaO\cdot7Al_2O_3\cdot3CaF_2$	SiO_2	$(Al_2,Mg_3)[Si_4O_{10}][OH]_2\cdot H_2O$	Al_2O_3	Fe_2O_3	CaO
Mass fraction (wt.%)	11	47.5	9.5	14	7	3	8

3.2 Preparation process

The basic preparation process can be divided into three parts including mixing the composite slurry, preparing aqueous foam, and mixing composite slurry and aqueous foam. The preparation system of ISF in field applications is schematically shown in Fig. 7. And the mainly devices of preparation system are the generating device and the self-made stirrer.

The self-made stirrer with the size of length (1.6 m), width (0.75 m), and height (1.2 m) runs at a three phase power of 660V. We admixed cement, fly ash, and accelerator powder together and got the blend. The water from the ground pool was injected into the blend by the water pipe and a strong convection and shear mixing will form under the movement of ribbon and spiral in the stirred tank. It enhances the degree of turbulence of the composite slurry and promotes rapid mixing. The water-solid ratio was controlled as 0.4.

The generating device of ISF developed by ourselves consists of foam generator and mixer, the size of which is length (1.7 m) x width (0.9 m) x height (1.2 m) and the working voltage is 660V. Some of the water was used to dilute the foaming agent with 70 times and the high pressure air with volume of 282m^3/h and wind pressure of 0.8Mpa provided by the air compressor was pumped into the home-made foam generator. The turbulent eddy is formed after mixing and enhanced by the porous medium, causing greater pressure drop. The more homogenous and denser aqueous foam is produced from down to up as the porosity of porous medium increases stepwise. Mixer consists of chamber and hollow spiral pipe inside it. The high-speed composite slurry drives the impellers to rotate, and then foam slurry is stirred and delivered by hollow spiral pipe with helical blades. Vortex streets in this process can completely go into turbulence and cause vortex according to certain frequency. The loss of kinetic energy acts on the mixtures and a large number of foam fluids are formed.

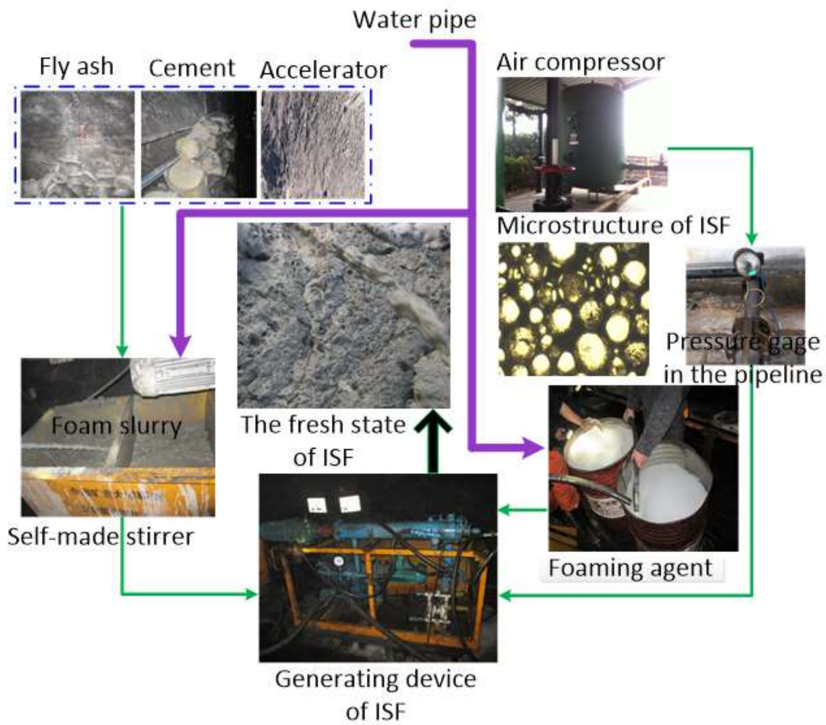

Fig. 7 The preparation system of ISF in field applications

3.3 The technical plan of site construction

The generating device of ISF and the self-made stirrer were placed in the air return roadway of 4303(1) working face, 50 m away from the air return corner. The preparation system was accessed to the mine pressure air supply system and water supply system. The produced foam fluid was injected to respectively seal the mining fractures behind hydraulic supports, the cavities of air return corner and intake airflow corner, and the fractures nearby the coal pillar by the 4 inch main grouting pipeline and 2 inch branch grouting pipeline. As shown in Fig. 8, two boreholes with 104mm in diameter were constructed and1 #, 2 # injection points were arranged after running the casing. The 3# injection point was set in the deep of the goaf near the coal pillar and the 4# injection point was set at the air return corner. Considering the possibility that the foam fluid may flow to the side of air return roadway, the waste rocks were packed and accumulated with the height of 1.5 m at the air return corner. The 5#, 6#, 7#, 8# injection points were arranged behind the hydraulic support every 30 m.

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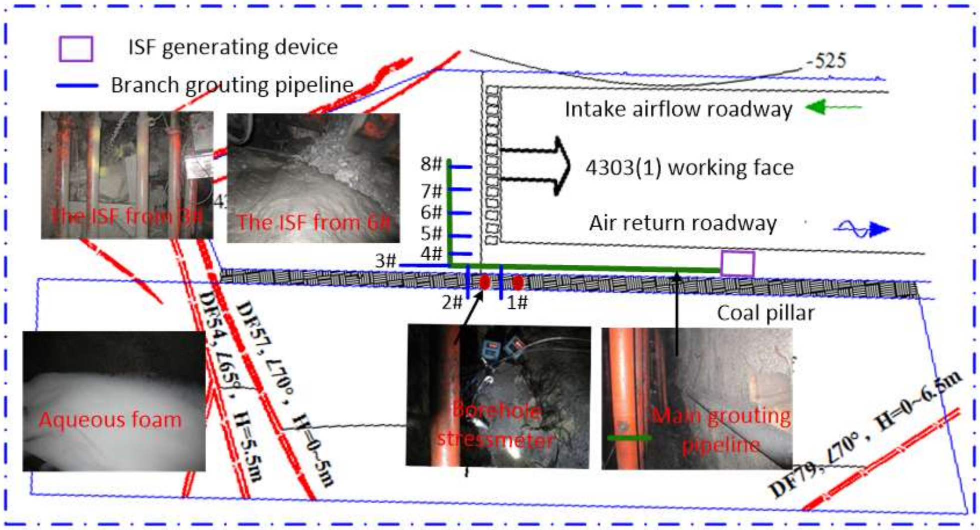

Fig. 8 The technical plan of site construction

3.4 The main technical performance parameters

After the foam fluid material has diffused into ISF in the fractures, it can isolate oxygen for spontaneous combustion of coal. When it evolved to the solidified state, it is a porous material whose macroscopic properties are strongly related to the microstructure of the foam. Besides, for coal mining, especially long wall mining, stress in the surrounding rock is the superposition of in-situ, mining-induced and supporting stresses. As a fracture filling material, ISF also needs to be able to withstand mining pressure. The movement of site cover rock caused the change of abutment pressure round the site, which indicated that the ISF was under compressive loading with different strain rates. So the main technical performance parameters for mining fractures filling are listed in Table 5.

Table 5 the main technical performance parameters for mining fractures filling

Name	Value
Stability coefficient	95%
Foam expansion ratio	5-7 times
Loss of fluidity time	10-30 min
Foam fluid density	465-825 kg/m^3
Dry density	250-400 kg/m^3
Compressive strength	0.72-1.6 Mpa
Thermal conductivity	0.0415-0.083 W/m•K
Closed porosity	66.89%
Scalability	No

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4 Application effect of inorganic solidified foam

After the foam fluids were injected into the fractures of coal pillar and goaf, its roles mainly include following three aspects: First, its ability of fracture penetration is strong and the air leakage will be isolated between the 4303(1) working face and the 4301(1) goaf. Second, the high temperature area in the goaf and coal pillar will be covered, cooled and oxygen insulated. At the same time, the ISF both belong to the pore structure materials no matter in the fresh state or after solidifying. The pore structure of the material itself has a very low coefficient of thermal conductivity, which can effectively block the spread of the hidden high temperature from fire area, inhibiting the regenerative heating to spontaneous combustion of surrounding float coal. Third, form the fresh fluid state to the solidified state, the ISF can consolidate the loose coal and rock. Its strength will increase by the more fully hydration reaction of the base materials as the growth of the time.[27, 28] So it can undertake the mining stress and effectively control the secondary deformation of the coal pillar for filling the fracture channel a long time. Therefore, in order to better reflect the intrinsic characteristics of ISF in the field application process, the targeted monitoring test of application effect was conducted. The mainly application effect consist of fracture filling and reinforcing, air leakage sealing, and index gases of coal spontaneous combustion inhibiting.

4.1 Fracture filling and reinforcing

(1) The layout and installation of borehole stress meter

When embedding the pipe for injecting the foam fluids, the 1# borehole and 2# borehole were constructed at intervals of 1m nearby the outlet of pipe, and then stress meter was buried into. The length of 1# borehole and 2# borehole was 2.5m and 1m, respectively. The angle was level and the height was 1m away from the roadway floor. The layout and system connection of the borehole stress meter in coal pillar were as shown in Fig. 9.

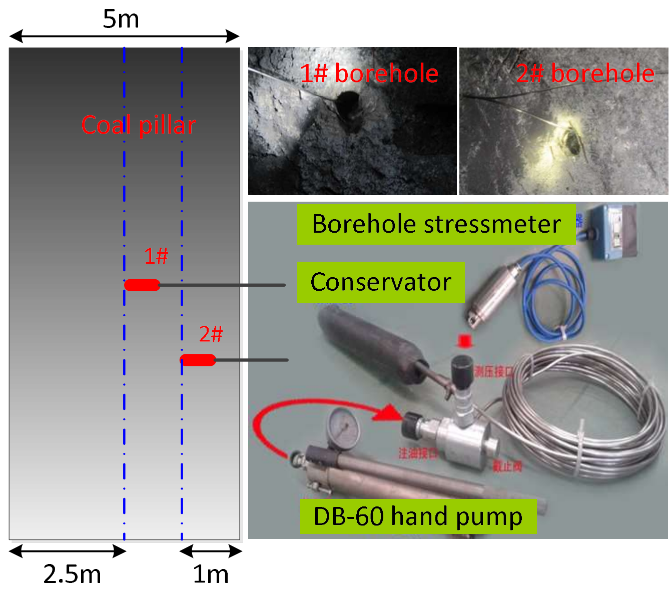

Fig. 9 The layout and system connection of the borehole stress meter in coal pillar

As shown in Fig. 9, the join operation steps for borehole stress meter system can be stated as follows. First, impregnate the sponge of GYW25 sensor with oil, at the same time, connect the manual pump and the filling interface of conservator with high-pressure tubing and the u-shaped card. Second, open the cut-off valve, close the reversing valve and pressure the conservator until the oil overflow from the pressure interface. Third, connect GYW25 sensor and pressure interface with a u-shaped card. Four, continue to pressure until the pressure is displayed at 3-5Mpa, open the directional control valve to let the oil flow back and repeat this operation for 3 to 5 times to drain the air in the pipe. Six, pressure with the manual pump again until the pressure is displayed at 3-5Mpa, close the shutoff valve, remove oil tubing connecting with the interface and the manual pump, and fixed the GYW25 sensor.

(2) The analysis of monitoring data

The advancing distance of the working face is 3.78 m every day except for encountering the special geology conditions. On the swing shift of February 3, 2015, in order to control the unusual methane emission from the 4301(1) and 4303(1) goaf, the 4 inch main grouting pipeline and 2 inch branch grouting pipeline were buried, and then the injection points were arranged as technical plan of site construction in Fig. 8. On night shift, February 7, the working face advanced to position of 1 # borehole. The injection was started and lasted for four hours. The whole construction process consumed 3 tons of cement, 2 tons of fly ash and 50 kg of foaming agent to produce about 27 m^3 of inorganic solidified foam. The actual effect of injecting the foam fluid into mining fractures is shown in Fig. 10. After the installation was complete, the monitoring data of the borehole stress meter was collected and recorded in each shift, accounting for a total of three times a day. The data acquisition of borehole stress meter lasted for 12 days, as shown in Fig. 11.

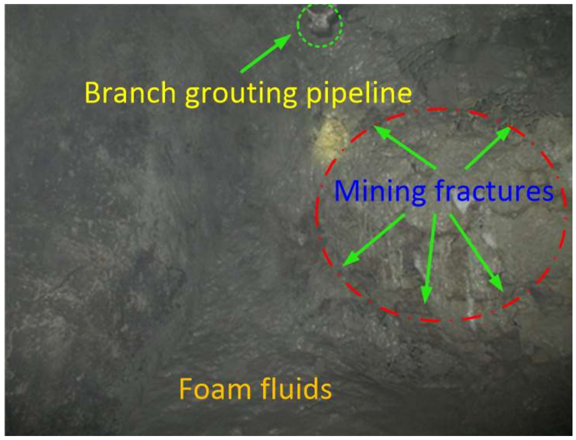

Fig. 10 The actual effect of injecting the foam fluid into mining fractures

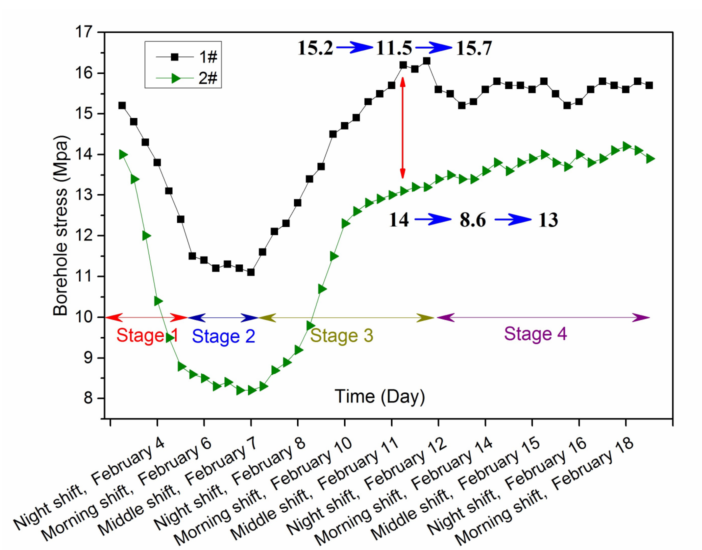

Fig. 11 The data acquisition of borehole stress meter lasted for 12 days

As shown in the Fig. 11, the overall trends of the 1# and 2# borehole stress are consistent, which can be divided into four stages. The first stage is downward, the second stage is relatively stable, the third stage is upward rapidly and the fourth stage is a fluctuant increasing process. Before the 4303(1) working face advanced to the drilling location (Night shift, February 5), the stress values of 1# and 2# borehole have been falling rapidly over time. Among which, the 1 # borehole stress reduced from the original 15.2Mpa to11.5Mpa and the 2 # hole stress reduced from the initial 14Mpa to 8.6Mpa. This is mainly because that initial layout position of the 1# borehole is 10 meters away from the working face. With the working face advancing, the coal pillar bear more and more concentrated stress and the plastic deformation occurs, leading to the vertical stress decreases gradually. There is a bigger drop of 2# borehole stress than 1# borehole stress mainly because the middle of the coal is looser than the both sides in the process of stress deformation. After the night shift, February 5, the stress did not continue to fall, which showed that the stress of coal pillar reached a new equilibrium under the completely crushed state. On the night shift, February 7, the foam fluids were injected into the coal pillar. The stress values have started to increase and reached to 15.7Mpa and 13Mpa, respectively, on the middle shift, February 11. The injected foam fluids can diffuse and permeate in the mining fracture channels, so the mining fractures nearby the borehole stress meter were sealed and filled. The foam fluids bond the loose coal and rock as a whole, meanwhile, its compressive strength ascends by the increasing hydration reaction over time. So the borehole stress increased. As time goes on, the stress values of the 1# and 2# borehole have maintained above 15.5Mpa and 13Mpa, respectively. It indicated that the ISF enhance the bearing stress ability of the coal pillar by transforming the stress state from two-dimensional to three dimensional.

4.2 Sealing the air leakage and control the methane emission

To observe the effect of sealing the air leakage after injecting the foam fluids, the readings of the u tube manometer installed in the sealing wall of 4301(1) goaf were recorded. The readings during the periods of February 4 to February 4 were counted three times (morning, middle and night) a day as shown in Fig. 12.

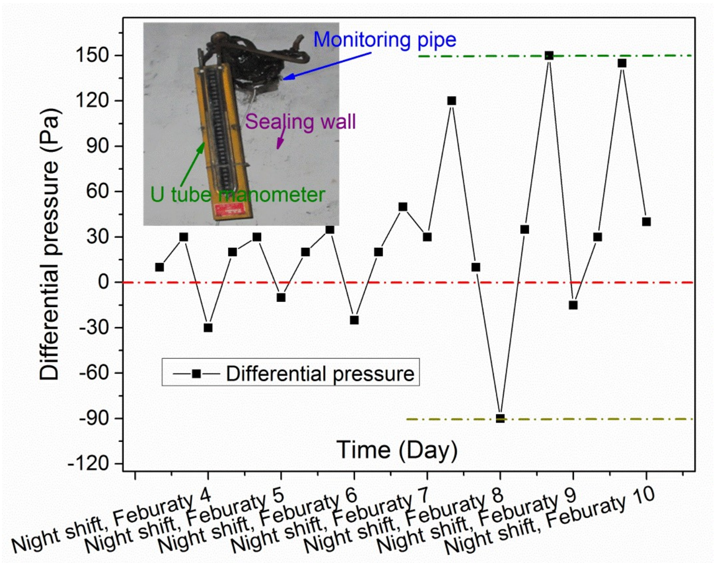

Fig. 12 Differential pressure changes of goaf before and after injecting foam fluids

From the Fig. 10, it can be clearly obtained that the ISF foam fluids can effectively seal and fill the mining fractures. Before the injection, the differential pressure inside and outside of the 4301(1) goaf fluctuates within the range of -30pa to +50pa, affected by the air pressure of the 4303(1) working face and the temperature. However, the differential pressure fluctuates obviously, basically maintaining between -100pa t0 150pa. What that all means, the foam fluids can seal the air leakage and the pressure in the 4301(1) goaf will not change with the outside air pressure.

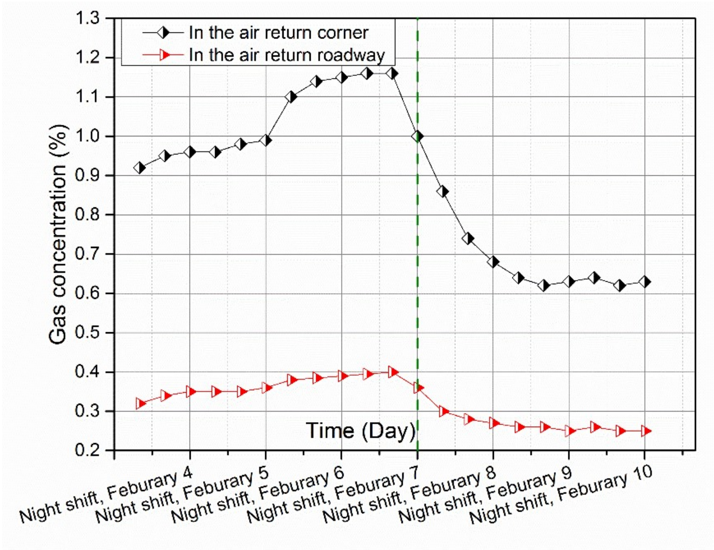

Fig. 13 The methane concentration in the air return corner and air return roadway before and after injecting the foam fluids

From Fig. 13, before the injecting the foam fluids (from February 4 to February 7), the methane concentration in the air return corner increased from 0.92% to 1.16%, which is exceeds the threshold of 0.8%, and the corresponding methane concentration in the air return roadway maintained between 0.32% to 0.4%. This is mainly because that the coal has been crushed as the working face advancing, the high concentration mine methane swarm into the 4301(1) goaf through the mining fractures of coal pillar, and the all the air leakage will converge in the air return corner under the influence of the ventilation pressure. At the scene, even if the high-pressure spray technology was adopted for methane dilution in the air return corner, a large number of original methane still flocked to the 4303(1) working face continuously. The methane concentration did not raise infinitely mainly because the differential pressure fluctuation of the air leakage and air volume increase from the originally planned 800m^3/min to 1200m^3/min. Therefore, on February, the foam fluids were injected into the fracture channels and to reduce methane emission. The methane concentration in the air return corner and air return roadway declined significantly to 0.86% and 0.28%, respectively, and the follow-up three days monitoring results show that the methane concentration has remained steady at 0.63% and 0.25% , respectively.

4.3 Inhibiting spontaneous combustion of coal

During the periods of February 4 to February 10, the methane sample in the 4301(1) goaf was collected into the bag by the automatic air exhaust pump. The methane composition of the methane sample was analyzed and the carbon monoxide concentration and oxygen concentration were listed in Fig. 14. Simultaneously, the carbon monoxide concentration in the air return corner was monitored as shown in Fig. 14.

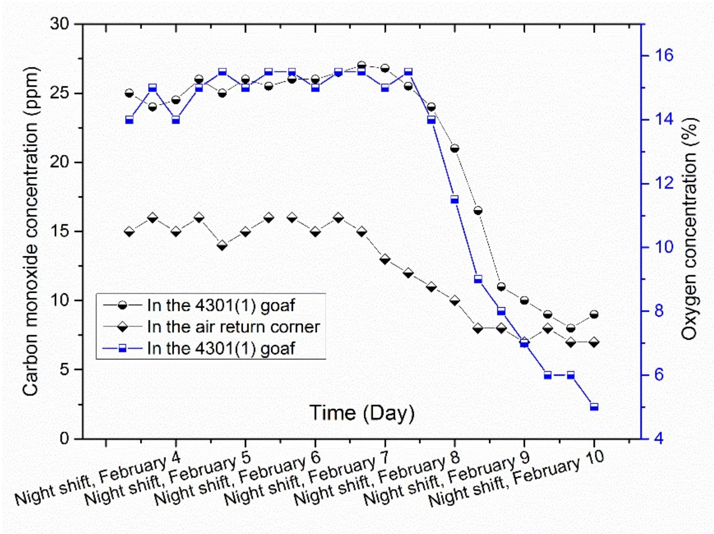

Fig. 14 The concentration change of carbon monoxide and oxygen in the goaf before and after injecting the foam fluids

From the Fig. 14, before the foam fluids injection, the oxygen concentration was between 14% to 15.5% and the carbon monoxide concentration increased from 24ppm to 27ppm. This is mainly because that the 4303(1) working face has advanced 102 m, which afford sufficient oxygen for the lower slicing coal in the 4301(1) goaf. In the meantime, the 4301(1) working face has been sealed and the heat accumulated gradually. So the float coal in the goaf started the oxidation in low temperature and the CO concentration increased, however, the other index methane of spontaneous combustion such as C_2H_4 and C_2H_6 did not generate because of the slow oxidation and heat accumulation. On night shift, February 7, the foam fluids injection started, however, the oxygen concentration did not descend timely with the value of 15.5% and the decrease range of carbon monoxide concentration was also inconspicuous. Until the middle shift, February 8, the concentration of carbon monoxide and oxygen started to decline promptly, and the values stabilized at 9ppm and 6%, respectively. This is mainly

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because that the mining fractures distribution is extensive, and intrinsic oxygen continues to maintain the short-term consuming for spontaneous combustion although the fractures nearby the coal pillar have been sealed. But the index methane concentration of spontaneous combustion declined more and more quickly after two shifts. It indicated that the foam fluids can block the oxygen supply and inhibit the spontaneous combustion of coal.

From the Fig. 14, before foam fluids injection, the CO concentration in the air return corner fluctuated within the range of 14-16ppm. The CO concentration declined rapidly and finally reached a stable level of 6ppm. This is mainly because that the foam fluids can seal the mining fractures 20 meters behind the air return corner. Thus, the CO in the 4301(1) goaf was difficult to flow into the air return corner of the 4303(1) working face. The source of CO concentration mainly contained two parts, the one part is from the 4301(1) goaf and the other part is from the 4303(1) working face. But the foam fluids can effectively control these two parts of CO sources.

5 Conclusions

(1) The methane emission of 4303(1) working face in mining process was predicted with the total quantity of 12.36m^3/min. The tendency of coal to spontaneous combustion was analyzed and the suitable index gases were selected with the result of CO, C_2H_4 and C_2H_2. By studying the methane source and the air leakage distribution influenced by the mining fractures, it can be obtained that the unusual methane emission and spontaneous combustion of coal coexisted.

(2) The preparation system of ISF in field applications is studied and the working principle of generating device consists of foam generator and mixer was expounded. The technical plan of site construction is explained as that the foam fluids was injected to respectively seal the mining fractures behind hydraulic supports (5#, 6#, 7#, 8#), the cavities of air return corner (3#, 4#), and the fractures nearby the coal pillar (1#, 2#).

(3) The overall trends of the 1# and 2# borehole stress were consistent. After the foam fluids were injected into the coal pillar, the stress values increased to 15.7Mpa and 13Mpa from the original 14Mpa to 8.6Mpa, eventually maintained above 15.5Mpa and 13Mpa, respectively. It indicated that the ISF enhance the bearing stress ability of the coal pillar by transforming the stress state from two-dimensional to three dimensional The methane concentration in the air return corner and air return roadway declined significantly to 0.86% and 0.28% from original 1.16% and 0.4%, and remained steady at 0.63% and 025% , respectively three days later. The differential pressure inside

and outside of the 4301(1) goaf fluctuates obviously, basically maintaining between -100pa to 150pa from the original range of -30pa to 50pa. The concentration of CO and O_2 in the 4301(1) goaf decline to 9ppm and 6% from previous 15.5% and 27ppm, respectively. The CO concentration in the air return corner finally reached a stable level of 6ppm from the range of 14-16ppm. What that all means, the foam fluids can seal the air leakage and inhibit spontaneous combustion of coal.

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