Mitigating Risks in Coal Mining

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Insufficient stability of the top plate at the corner of an easily combustible coal seam comprehensive mining face may lead to a natural fire within the goaf. While corner sealing is crucial for minimizing air leakage, current sealing methods struggle to effectively prevent such leakage. Additionally, the distribution characteristics of the oxidation zone in the goaf after sealing are unclear, making it difficult to control the extent of the oxidation zone.

air leakage at the corner of the working face inorganic paste filling material filling and sealing

1. Introduction

China possesses substantial coal reserves and has traditionally relied on coal as its main energy source. The progress of the coal industry is crucial for the nation's economic growth [1][2]. Nevertheless, the coal industry faces a range of obstacles, including water, fire, gas, and roof collapses during mining, limiting its development. Among these challenges, the spontaneous combustion of residual coal in the goaf, triggered by air leakage at the working face corners, is a major issue that impacts the safety of coal production in mines [3][4][5].

The occurrence of spontaneous combustion disasters in goaf areas is often attributed to the self-ignition of residual coal upon exposure to oxygen [6]. Through the collapse pattern of the goaf roof [7][8][9], a suspended structure forms at the corner of the working face due to the support provided by the coal wall and hydraulic supports. This region exhibits a high void ratio, designating the two corners as the primary pathways for air leakage within the goaf. Effectively addressing air leakage at the corners of the working face has consistently posed a significant challenge in mitigating spontaneous combustion and fires originating from residual coal in goaf areas [10][11]. Understanding the relationship between internal airflow and resistance within the goaf area indicates that increasing resistance can fundamentally diminish air leakage [12]. Filling and sealing the corners of the working face constitute reliable methods for enhancing resistance. Safely and efficiently sealing the pathways of air leakage at the corners of the working face to reduce air infiltration into the goaf has become a critical aspect of ensuring the secure extraction of coal in mining operations.

The currently prevalent methods for corner sealing mainly consist of building cement walls and applying high-molecular-weight materials. However, these sealing techniques face problems, such as an insufficient sealing efficacy, an extensive construction effort, and high-molecular-weight materials being prone to self-ignition. In this context, the potential use of inorganic paste materials with proper fluidity, strong self-supporting properties, and appropriate strength for filling corners in the working area and sealing the main air leak passages in the goaf should be evaluated.

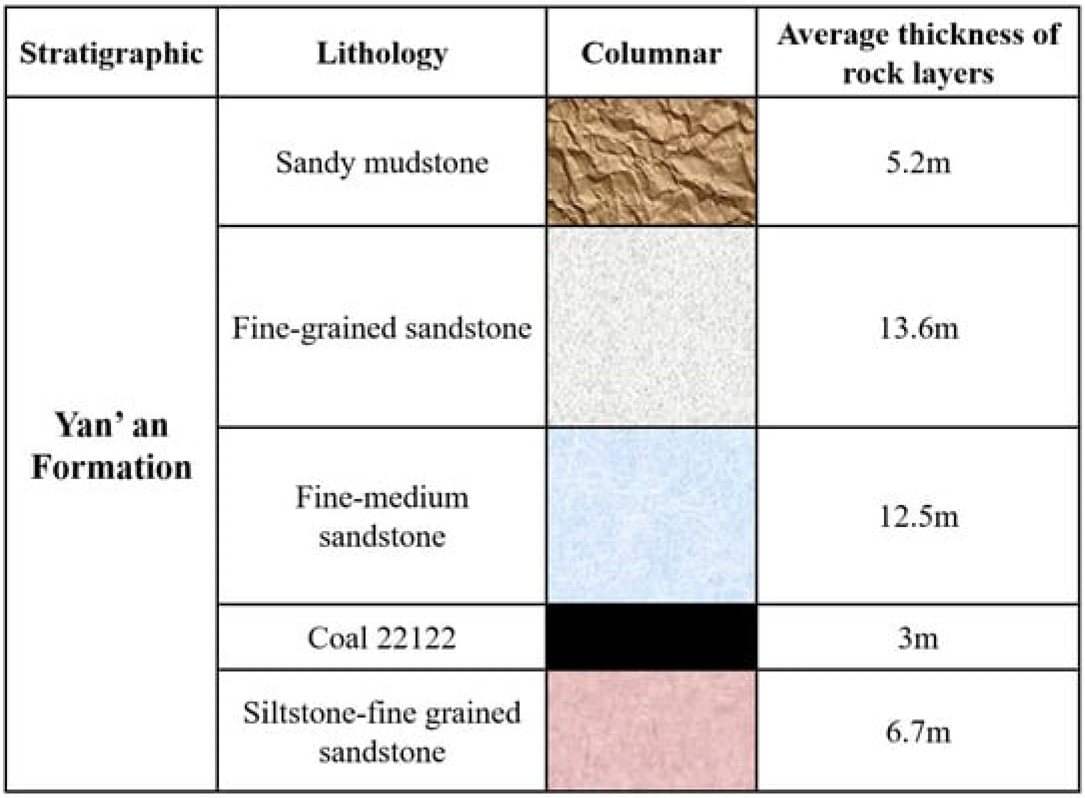
Research into inorganic paste materials for use as coal mine filling materials was initiated by scholars in the 1950s [13][14]. Different types of inorganic filling materials, including fly ash paste, high-sand filling materials, foam cement, inorganic-cured foam materials, and ultra-high-water materials, were studied and provided a solid foundation for practical applications [15][16]. Huang Xingli and colleagues [17] utilized inorganic foaming filling materials to seal ventilation channels in the goaf, using mobile grouting technology. This refined inorganic filling material significantly reduced the initial setting time, effectively addressing the issues of spontaneous combustion and fires in coal seams. Feng Guangming [18] developed ultra-high-water filling materials and successfully applied them to fill mining working faces, tackling the challenge of high filling costs. Liu Yong [19] conducted experiments on high-sand filling materials, using water, cement, fly ash, and wind-blown sand as inorganic filling aggregates, and determined the optimal concentration ratio suitable for water-preserving mining, significantly impacting water-preserving mining practices in western mining areas. Zhao Xuefei [20] utilized various fine-tail grains of sand as filling aggregates, examining the filling performance of cemented paste materials under different aggregates and additives, and found that substituting cement with high-alumina clay resulted in minimal changes in the compressive strength of the filling body while gradually enhancing stability in later stages. Zheng Juanrong [21] and collaborators introduced different types of early-strength agents to tailings cemented paste filling materials and discovered that Na_2SO_4 and NaOH early-strength agents had superior effects. Zhang Xuebo [22] used advanced Fluent numerical simulation software to conduct research on air leakage in the goaf. The simulation results led to the application of a custom test scheme using tracer gas SF6 on the fully mechanized mining face, revealing the air leakage patterns of the working face.

Inorganic paste filling materials have become the preferred choice for mining operations and the sealing of working faces. However, practical challenges arise when using these materials to seal corner leakage paths at working faces, mainly due to their high cost and low recovery rate. Therefore, there is a continuous need to develop new types of inorganic paste filling materials that consider the geological conditions of mines and the storage conditions of surrounding materials. The objective of this development is to provide an efficient and reliable sealing solution for corner leakage paths at working faces [23]. The sealing of corner leakage paths can significantly impact the pressure field within the goaf. The effects of filling at different corners and intervals can vary greatly, affecting ventilation patterns and gas distribution in the goaf, as well as directly influencing the cost of filling and normal mining operations at the working face [24][25][26]. Currently, the distribution characteristics of the oxidation zone in the goaf under different filled corners and intervals between two corners are not well understood, posing a challenge in establishing rational and effective corner-filling strategies for working faces.

2. Mitigating Risks in Coal Mining

The Cuncaota II Mine is located in the Yijinhuoluo Banner, Ordos City, within the Inner Mongolia Autonomous Region. The coal seams extracted from this mine are Type I, which makes them prone to spontaneous combustion. They have a significant mining height and long working faces, with relatively fewer collapses in the upper and lower triangular areas. However, there is a considerable amount of residual coal near the two roadways in the goaf, posing a significant risk of spontaneous combustion. Classified as a low-gas mine, the risk of surpassing gas pressure limits is relatively low. The main safety concern affecting mine production is the spontaneous combustion of residual coal in the goaf due to air leakage. Therefore, immediate measures are necessary to mitigate the likelihood of spontaneous combustion in the goaf and ensure the safety of mine production.

The 22,122 working face is located in the No. 1 mining area, spanning 835.5 m in length and 340.9 m in width, covering a total area of 284,821.95 m^2. The coal seam varies in thickness from 2.14 m to 4.81 m, with an average thickness of 2.93 m. The roof of the working face consists mainly of sandy mudstone and siltstone, followed by mudstone and medium-grained sandstone, with localized occurrences of fine-grained sandstone and coarse-grained sandstone. The floor primarily consists of siltstone and fine-grained sandstone. The stratigraphic column of the working face is shown in **Figure 1**. In the auxiliary haulage roadway of the 22,122 area, the roof consists mainly of continuous medium-grained sandstone, with good rock layer integrity and reduced susceptibility to collapse during mining operations. However, there is a significant issue of air leakage at the two corners of the working face. Currently, measures such as wind curtains and cement bag walls are primarily used to mitigate air leakage. The 22 coal seam is characterized by its overall black coloration with black-brown streaks. The primary constituents of the coal rock include dark coal, bright coal, and some occurrences of cannel coal and vitrinite. The coal exhibits an asphalt luster, featuring a uniform and banded structure, blocky texture, extensive crack development, semi-hardness, and a propensity for spontaneous combustion. The coal seam has a natural ignition period of 42 days, with flame lengths exceeding 400 mm, and the coal dust within the seam possesses explosive properties.



Stratigraphic	Lithology	Columnar	Average thickness of rock layers
Yan' an Formation	Sandy mudstone		5.2m
	Fine-grained sandstone		13.6m
	Fine-medium sandstone		12.5m
	Coal 22122		3m
	Siltstone-fine grained sandstone		6.7m

Figure 1. Stratigraphic column of the 22,122 working face.

To fully grasp the impact of corner filling on changes in the gas concentration in the goaf, the oxygen concentration in the goaf is monitored using a 260 m long 2-inch seamless steel pipe. This pipe is positioned in the direction of the main withdrawal channel, starting from the end position of the inlet and return air lane of the 22,122 working face. By employing the oxygen concentration method, the approximate range of the oxidation zone in the goaf is determined. This method relies on measuring the oxygen concentration at various distances from the goaf to the working face. Areas with an oxygen concentration greater than 15% are classified as heat dissipation zones. Areas with an oxygen concentration between 15% and 5% are considered oxidation spontaneous combustion zones. Lastly, areas with an oxygen concentration below 5% are identified as asphyxiation zones. Sampling probes are strategically placed at 25 m intervals, starting from the corner of the working face. Each intake and return airway has three probes, labeled as “Inlet 1,” “Inlet 2,” “Inlet 2,” “Return 1,” “Return 2,” and “Return 3”. To protect the probes from damage, probe protection devices are utilized, and seamless steel pipes are connected using flange plates to ensure strong connections. Through sampling and an analysis of gas concentration data, it is observed that, on the intake side of the 22,122 working face, the oxygen concentration decreases to below 15% at a distance of 134 m from the working face, indicating entry into the oxidation zone. At a distance of 229 m, the oxygen concentration further decreases to below 5%, signifying entry into the asphyxiation zone. The oxidation zone is approximately 95 m wide. On the return side of the goaf, the oxygen concentration decreases to below 15% at a distance of 42 m from the working face, entering the oxidation zone. At a distance of 185 m, the oxygen concentration drops below 5%, indicating entry into the asphyxiation zone. The oxidation zone on the return side has a width of around 141 m. **Figure 2** illustrates the situation of the 22,122 working face and the distribution diagram of the “three zones” of spontaneous combustion in the goaf.

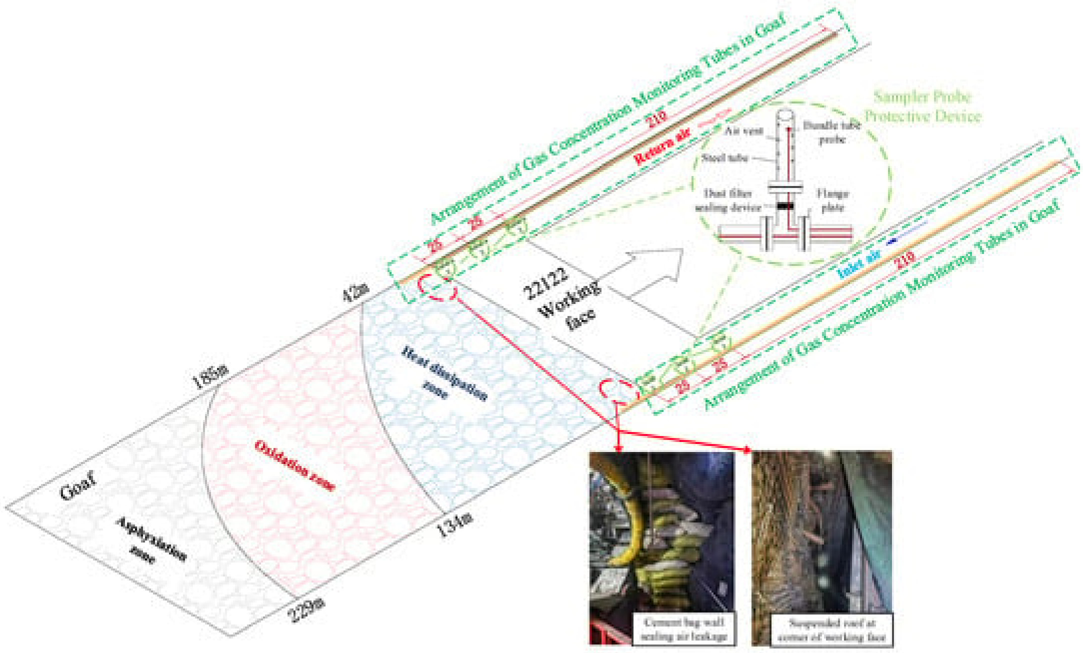


Figure 2. Conditions of 22,122 working face and distribution diagram of goaf oxidation zone 3 experimental analysis of mountain sand paste filling material.

Based on the above analysis, it is evident that there is a significant issue of air leakage at the corners of the 22,122 working face. The current sealing techniques are not effective, resulting in a considerable amount of airflow entering the goaf. Additionally, in the goaf of the 22,122 working face, particularly on the return side, the width of the oxidation zone is excessively large, leading to a heightened risk of spontaneous combustion in the goaf. It is essential to implement effective sealing methods at the corners of the working face to minimize air leakage into the goaf, decrease the width of the oxidation zone, and ensure safe mining operations.

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