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Present situation and prospect of coal-based solid waste foam concrete material

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Abstract: *This study explores the significance of coal in China's energy security. And at the same time, noting the fact that the extensive coal mining activities also generate a considerable amount of solid waste, posing significant environmental challenges. This paper conducts a comprehensive analysis of coal-based solid waste filling materials, emphasizing their efficacy in applications such as filling material, foundation stabilization, and the prevention of ground collapse. Furthermore, the study explores potential applications of these materials in other contexts and outlines future research directions to address the environmental impact of coal mining while harnessing its energy potential.*

Keywords: *Coal based solid waste; Filling materials; Concrete; Foamed Concrete*

1. Introduction

China's energy endowment is characterized by abundant coal resources, relatively scarce oil, and limited natural gas, making coal a pivotal basis for national economic development. In recent years, coal production has consistently set new records, reaching 4.13 billion tons in 2021, 4.56 billion tons in 2022, and 4.66 billion tons in 2023, according to National Bureau of Statistics data. Imported coal also surged by 61.8% year-on-year to 470 million tons in 2023. The National Energy Administration's Energy Work Guidelines emphasized the need to consolidate the foundation of energy supply security while accelerating the transformation to green and low-carbon energy. In this context, coal mining faces multiple challenges, including ensuring energy security, protecting the ecological environment, and reducing carbon emissions. Therefore, the green and low-carbon development of coal resources is imperative[1].

One significant green and low-carbon mining technology is coal-based solid waste filling mining. This technology offers technical advantages in controlling surface subsidence, protecting the environment, utilizing coal-based solid waste, and achieving energy conservation and emission reduction[2]. It has realized safe mining, addressed issues such as surface subsidence, groundwater loss, underground gas discharge, and land resource destruction, and reduced the energy consumption and emissions associated with coal transportation and well lifting. Furthermore, this technology aligns with China's "carbon peak, carbon neutral" strategic goal and supports the green and intelligent coal mining, efficient, clean, and low-carbon utilization industry's key research direction and green development concept. This promotes the coal industry's future development towards high quality, environmental protection, greenness, and low carbon emissions.

2. Evolution and Development of Backfill Mining Technology

Coal-based solid waste includes coal gangue, fly ash, gasification coal cinder, powdered coal, etc.; collectively called coal-based solid waste, the solid waste is mainly disposed through landfill and storage, and the accumulated coal-based solid waste occupies a large amount of land and affects the ecological environment. The coal gangue shower water will pollute the surrounding soil and groundwater, and coal gangue contains certain combustible, under the appropriate conditions, coal gangue spontaneous combustion, coal gangue combustion will make the mining area near the body by certain harm, at the same time, the combustion of coal gangue will also produce a large number of sulfur dioxide, carbon monoxide, hydrogen sulfide and other harmful gases, cause certain pollution to the atmospheric environment. Coal gangue is also rich in heavy metals. If these heavy metals penetrate the water, they

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will make the water toxic and cause serious harm, and the mineral content of heavy metals in coal gangue will be more. Once the water needed around human beings is damaged and polluted, the water will be harmful with the help of various food chains, and may cause irreversible harm to the ecological environment.

At present, most of the coal mines take the coal-based solid waste to other enterprises for comprehensive utilization, to deal with the coal-based solid waste produced in the production process. However, the coal gangue in the mining area still accumulates in large quantities, which occupies the land and can easily cause spontaneous combustion. Although China has made some progress in the utilization of coal gangue, the normal production of the mine still poses a great threat to the production and life of the residents around the mining area. At present, the control of coal gangue is an important measure for the coal mining industry to adapt to the green and low-carbon development, and it is an inevitable trend of the development of low-carbon economy. The ground gangue stacking yard will not be built, and the production of coal gangue will be reduced or prohibited, but the fundamental problem has not been really solved.

After several decades of evolution, filling mining technology has emerged as a pivotal component in the coal mining process, transitioning from the use of waste stone to advanced water sand filling methods. This green mining approach has kept pace with the expanding mining industry, evolving through various stages such as paste filling, stone mortar cement filling, and full tailings cement filling. China's coal industry's rapid growth has fueled continuous advancements in this technology, ensuring it remains contemporary. Globally, countries like Canada, South Africa, and Germany, with their abundant mineral resources and mature mining technologies, have played significant roles in the development of foreign backfill mining techniques. Canada, in particular, has seen an increase in the use of impact sand as the primary filler since the 1930s, achieving significant advancements in filler materials and technologies by the 1990s. South Africa, rich in coal resources, initiated filling mining technology in the early 1980s, primarily adopting cement-based filling processes, which evolved into high-concentration pipe filling and paste filling methods.

In China, the development of filling mining technology has undergone remarkable transformations, starting with significant improvements in coal mining efficiency in the northern regions around the 1970s. By the 1980s to 1990s, China's filling mining technology had caught up with international standards, entering a new era of modern filling techniques such as paste filling, rock grouting, solid filling, and gangue-based high-water filling. Today, China boasts a sophisticated filling mining technology system, encompassing research on filling material ratios, geological stress relationships, force mechanics theory, and advancements in filling equipment and processes. This comprehensive system allows for the selection of the most suitable filling method based on geological conditions, mine properties, and economic factors, emphasizing that the filling mining approach is not a one-size-fits-all solution but rather a tailored method adapted to individual mine requirements[3].

3. Utilization methods of coal-based solid waste

Low-value of gangue and fly ash can be paved and buried underground. Many research institutions at home and abroad have done a lot of tests to demonstrate the feasibility of coal gangue and fly ash as fillers. On the main highways of some European and American countries, coal gangue has been used as a filler in the highway subgrade or base level, and the corresponding technical standards have been formulated. Some coal gangue is paved on the section of 83.37 meters from Xingfen Expressway to Hebei and Jin boundary in Xingfen, China. According to a lot of practical experience, it is found that the strength, stability and bearing capacity of the subgrade formed are very good, which can meet the requirements of relevant specifications. When the particle size ratio, moisture content and compaction degree of coal gangue solid waste all meet the appropriate requirements. However, there are problems such as limited utilization scale, uncentralized utilization and possible environmental pollution. Comprehensive mechanized filling coal mining process and cemented filling coal mining process are used for underground filling, and green mining of coal mine is realized. However, due to the restriction of filling effect requirements, equipment process and automation degree, the downhole filling technology still cannot meet the needs of coal-based solid waste treatment at the present stage.

1) Filling materials: Coal gangue can be used as filling materials for filling the mine, subgrade, building foundation and other parts, playing a role in stabilizing the foundation and preventing soil erosion.

2) Building materials: Coal gangue and fly ash can be used for the production of bricks, cement,

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glass and other building materials, and the aluminum, silicon and other elements in these solid waste are important raw materials.

Using coal gangue as fuel power generation can solve the problem of gangue accumulation to a certain extent, but the calorific value and carbon content of gangue are relatively low, and a large amount of fly ash will be produced after combustion, which also harms the living environment of human beings. In contrast to coal gangue after artificial forging and excitation after its mineral composition and atomic arrangement changes, let it has certain activity after the cement used as volcanic ash mixture, not only can solve the negative impact of coal gangue on the environment, can also replace part of cement, reduce cost, at the same time reduce the environmental pollution problems in the cement industry production. The harmless comprehensive utilization of coal gangue has gradually emerged in China since the 1980s. So far, coal gangue building materials and products are the most important application direction. Huang Fulong's study showed that replacing 5% of cement with coal gangue can stimulate the early and late strength of cement to a large extent. Replacing 30% cement with gangue had a 3d compresstrength ratio of 0.67 and 28d 0.79. Shi Tao, Wang Peiming, etc. made in-depth research on the hydration process, hydration products, microscopic morphology and hydration mechanism of coal gangue cement based materials, and the results showed that coal gangue can play a beneficial role in improving the structure of cement stone and improving the long-term strength of hardened cement stone. After studying the microstructure of fine aggregate mortar of coal gangue with different fineness moduli, Dong Zuochao found that the mortar with small fineness modulus had high hydration degree and more hydration products, and with the growth of age, the volcanic ash effect of fine aggregate of coal gangue was more obvious.

4. Prospect and prospect of coal-based solid waste filling mining

4.1 Filling materials and filling system

Combined with coal-based solid waste filling mining technology present situation and filling mining rock control theory, the industrial intelligent upgrade, coal-based solid waste scale disposal and resource utilization, deep mining and "double carbon" strategy implementation of new demand and situation, considering the filling technology using underground mining space, coal-based solid waste treatment and multiple filling material utilization way of key technology characteristics. Coal-based solid waste filling mining technology, including method improvement, equipment update and process optimization, needs further reform and upgrading, and more initiative in carbon storage and functional filling.

At present, the use of coal-based solid waste as filling materials is still the mainstream, but with the progress of filling mining technology and the improvement of environmental protection requirements in China, the filling materials will develop towards diversification in the future. In addition to coal-based solid waste, other wastes, such as construction waste and industrial waste, can also be considered as filling materials to reduce costs and reduce environmental pollution. In addition, the research and development of new filling materials, such as polymer materials, gel materials, will also be the future development trend.

An important direction of the future development of filling mining technology is intelligent filling system. By introducing the Internet of Things, big data, high score remote sensing, artificial intelligence and other technologies, the intelligent ratio of filling materials, the real-time monitoring of the filling process, and the evaluation of filling effect and other functions can be realized, so as to improve the efficiency and filling effect of filling mining.

With the improvement of filling materials and filling technology in China, the filling process will also be optimized. In the future, new filling processes will be developed, such as high concentration filling and rapid filling, to improve the filling efficiency, reduce the filling time and reduce the filling cost. At the same time, the rules of stress field and deformation field in the filling process are studied, the filling process parameters are optimized, and the stability and carrying capacity of the goaf after filling are improved.

With the Internet of things, big data, high remote sensing, artificial intelligence technology such as rapid development in China, coal mining in the future in the direction of intelligent, unmanned development, future filling mining technology will be an intelligent mining technology, can realize the coal mining, filling, transportation automation and intelligent, improve the efficiency and safety of filling mining. At the same time, unmanned operation will also become an important trend of coal

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mining in the future, reducing the amount of manual operation and reducing safety risks.

4.2 Intelligent and efficient filling coal mining technology for coal-based solid waste solid state

With the rapid progress of the intelligent construction process of the coal industry, China's demand for coal-based solid waste treatment is also increasing. This puts forward new requirements for the treatment capacity of coal-based solid waste, for the mining process, and for the production capacity of single working surface. In view of the new engineering background and requirements of large mines in China, such as the fast speed of coal mining process, the large emission of coal gangue, the fragile ecological environment of the mining area, the low surface protection standard, and the insufficient capacity of dense filling mining mode, it is particularly urgent to improve the intelligence and high efficiency of filling mining. Coal-based solid waste filling and mining technology uses intelligent equipment to realize intelligence. Intelligent perception of process parameters, independent adjustment of equipment status, automatic execution of the charging process, independent judgment of the charging effect, and real-time display of the charging process. The development of intelligent filling mining technology is to achieve the goal of efficient mine production, mining system integration, automatic equipment operation, independent production process, accurate rock control, simplified labor organization and large-scale coal-based solid waste treatment. This technology is also an effective solution, which can improve the work efficiency and economic benefits of traditional filling mining areas, and meet the important needs of digital and intelligent upgrading of China's energy industry. The intelligence degree of coal-based solid waste filling and mining technology is still in a relatively early stage. Research on the design of intelligent filling self-drive process, sensing method of filling equipment, independent identification method of equipment, parallel linkage and connection mechanism of mining and filling system, complete equipment of intelligent filling and system research and development, to improve and optimize the intelligent filling mining technology of coal-based solid waste and improve the intelligent level of coal-based solid waste filling mining process. It is necessary to overcome the difficulties brought by key technologies such as high flow material transportation, underground logistics dispatching and transportation of large mines, super large mining face and efficient landfill and excavation collaborative operation, and optimize the efficient realization of coal waste landfill and mining technology. Research and develop high-flow and wear-resistant vertical feeding equipment for feeding and transportation, develop intelligent flow monitoring system for feeding and transportation, develop transportation equipment with high power, high strength and high resistance, and optimize the mining and charging process. It provides theoretical and technical guidance for the large-scale disposal of coal gangue in mining areas in China.

4.3 Optimization of the filling process

As China's filling materials and technologies advance, the filling process is poised for optimization. Future developments will encompass innovative filling techniques, such as high-concentration filling and rapid filling, aimed at enhancing filling efficiency, shortening filling time, and reducing filling costs. Concurrently, investigations into the stress field and deformation field dynamics during the filling process will lead to the optimization of filling parameters, thereby bolstering the stability and load-bearing capacity of the goaf post-filling. On the other hand, in line with China's heightened environmental governance standards, coal-based solid waste filling and mining technologies will increasingly prioritize environmental protection. Efforts will focus on researching and developing eco-friendly filling materials, enhancing the utilization of coal-based solid waste resources to mitigate their environmental impact. Additionally, rigorous environmental monitoring and treatment measures will be implemented during the filling mining process to minimize its ecological footprint.

5. Conclusion

(1) For a long time, coal resources have played a pivotal role as a ballast, a driving force, and a strategic support in the national economy. Nowadays, coal-based solid waste treatment and landfill mining technology are confronting novel opportunities and challenges, including industrial intelligent upgrading, large-scale disposal of coal-based solid waste, deep mining, the "double carbon" strategy, and the resource utilization of coal-based solid waste. It is imperative to delve into the theory and technology of coal-based solid waste filling mining.

(2) Over the past decades, filling mining technology has evolved from merely a means of solid waste disposal to a low-energy-consumption method for preventing surface subsidence, which

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effectively safeguards the ecological environment. Additionally, this crucial technology has facilitated green mining and intelligent mining in modern mines, unlocked more low-grade unmined coal resources, and enhanced the coal recovery rate. The dissemination and adoption of filling mining technology are of utmost importance to the construction of modern mines in China, yielding substantial benefits in both the economy and the environment.

(3) Current research endeavors are centered on enhancing the efficiency, scale, and intelligence of coal-based solid waste filling mining technology. Furthermore, there is an exploration of its extended applications in the realm of coal and related resources co-mining, as well as carbon storage. The primary focus of current research also includes the promotion and application of coal-based solid waste filling mining technology. The main development directions encompass, but are not limited to, intelligent and efficient landfill of coal-based solid waste, underground residual filling treatment, deep filling technology, carbon storage utilizing coal-based solid waste wells, underground application of practical coal-based solid waste materials, and other pivotal technologies. The overarching goal is to develop a systematic and diversified theory and technology system for coal-based solid waste filling mining in coal mines.

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