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Analysis of the Development of Support Technology for Coal Seam Mining Roadways

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Abstract: In the process of coal mine safety production, the application of coal roadway support technology is extensive, as it not only enhances the stability of the support system but also improves support efficiency. It is essential to conduct research on the rational application of support technology to effectively stabilize the geological structure of coal mines. This paper analyzes the current application status of roadway support technology in coal mine support, identifies common issues and influencing factors in existing mine support systems, and proposes the selection of design schemes based on specific coal roadway conditions. By improving support effectiveness, implementing innovations, developing intelligent mining equipment, and establishing a support monitoring system, this study aims to provide a robust guarantee for the coal mining industry.

Keywords: Mining lanes; Roadway support technology; Bolt support; Application status

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1. Introduction

Coal mines, as one of China's primary energy sources, face increasingly complex geological conditions in mining roadways. Consequently, support technology for coal seam mining roadways has become a critical issue that cannot be overlooked. In recent years, coal roadway support technology has advanced rapidly. During coal seam mining operations, this technology not only optimizes support systems but also enhances their stability, providing robust assurance for the efficient advancement of coal mining operations.

2. The development of the theoretical framework for coal mine support technology

China's coal resources have now entered a phase of sustainable development. As coal seam geological conditions become increasingly complex, the support technology for roadways during tunneling has become particularly critical. Chinese experts and scholars have established a relatively comprehensive theoretical framework for roadway support technology, which provides effective guidance in production processes. This framework encompasses the following theoretical approaches:

2.1. Key circle theory

Kang Hongpu proposed the Key Circle Theory, which analyzes the stress distribution characteristics and variation patterns of roadway surrounding rock by examining the influence of key bearing circles in circular roadways under elastic and plastic stress states, based on the structural types of coal mine surrounding rock. This theory reflects the stress distribution features of surrounding rock by determining the distribution of key bearing layers under different original rock stresses and strength conditions. Furthermore, the Key Circle Theory enables the determination of stress control for roadway maintenance [1]. Such as pre-mining, cross-tunnel mining, and pillar-less support.

2.2. Loose ring support theory

Dong Fangting et al. proposed the theory of loose zone support. By classifying loose zone rock masses and elucidating the mechanism of shotcrete support, they discovered that the size of the loose zone determines both the shotcrete support mechanism and the state of the surrounding rock. The size of the loose zone results from the interaction between rock stress and rock strength. Corresponding support techniques are proposed based on the size of the loose zone [2].

2.3. Theory of reinforced rock mass strength

Hou Chaojiong et al. proposed the theory of rock mass strength enhancement, discovering that after rock mass reinforcement with rock bolts, the strength of the anchored zone increases. This effectively reduces the radius of the plastic zone and fractured zone in the tunnel's surrounding rock, as well as surface displacement of the tunnel, thereby maintaining tunnel stability. Anchors can enhance both the peak strength and residual strength of surrounding rock, thereby improving its mechanical properties. This fundamentally reveals the mechanism of action for anchor support [3].

2.4. Theory of self-supporting arch structures

Huang Qingxiang et al. proposed the theory of limit self-stabilizing equilibrium arches. Based on the mutual influence among the tunnel's floor, sidewalls, and roof, they revealed that the rock mass within a self-stabilizing parallel arch consists of caving rock and limit equilibrium rock, which are the targets for support control. Tunnel support should be designed according to the limit self-stabilizing equilibrium circle. Anchor rod placement should follow the "vertical rock face principle, uniform distribution principle, and radial principle" [4].

2.5. Butterfly damage theory

Zhao Zhiqiang et al. proposed the butterfly-shaped failure theory for roadway surrounding rock, elucidating that failure manifests in three forms: circular, elliptical, and butterfly-shaped. They explained variability and micro-effectiveness of support from three aspects: stress environment, surrounding rock conditions, and support resistance. The study also explored application prospects in engineering fields such as roadway surrounding rock control and dynamic hazard prevention [5].

Furthermore, integrating theoretical foundations, coal mine longwall support technology must comprehensively consider the structural properties of surrounding rock—progressing from simple engineering analogies and theoretical calculations to numerical simulations. Based on specific working face conditions, support schemes tailored to each face should be designed to ensure construction safety in longwall mining, enhance rock mass stability, and facilitate a more thorough understanding of roadway conditions.

3. Current status of application in coal mine support technology control

Due to the numerous and varied faults in the coal-bearing strata beneath the mining roadways, significant safety hazards arise for coal production. During roadway support operations, improved anchor rod support technology is first employed to optimize roadway structure. With continuous scientific and technological advancement, roadway support techniques have diversified while integrating theoretical foundations. For instance, coordinated approaches such as "rock bolts + short rock bolts," "rock bolts + rock bolts + W-shaped steel bands + anchor mesh," "sprayed concrete with anchor bands and mesh + hollow grouting rock bolts," and "rock mass reinforcement-pressure relief-enhanced support" have been employed. These methods undoubtedly aim to better address issues like deformation in mining roadways, rock mass stability, and ground heave. Some scholars, drawing from elastic-plastic mechanics, rock mechanics, and rheological mechanics, have conducted research by integrating rock mass structures with numerical simulations, similarity testing, and field measurements. This approach not only optimizes support structure designs but also defines the optimal range for bolt support dimensions in working faces. By selecting the most efficient configuration, it achieves roadway stability with minimal cost investment, delivering enduring and reliable support performance for engineering projects.

3.1. Bolted support technology

Taking a mine in Shandong as an example, based on traditional non-full-length anchors, the use of fast-setting resin combined with grouting reinforcement effectively fills anchor cracks, achieving prestressed grouted support effects. The full-length prestressed grouting support method increases overall support strength as anchor rod length increases and spacing decreases. This effectively enhances grouting reinforcement, achieving optimal control of the surrounding rock. Compared to the original support scheme, surrounding rock deformation is significantly reduced, and the effectiveness of the anchor-grout support technology is improved [6].

Therefore, adjusting anchor support parameters based on the actual conditions of each coal mine working face to reinforce the surrounding rock and reduce deformation will enhance the safety of the roadways.

3.2. Combined support technology

Integrated support technology is suitable for mining roadways with complex geological conditions, poor surrounding rock stability, and high in-situ stress. As the fractured zones of surrounding rock near faults in coal mines expand, mining depths increase, and the surrounding environment of mining areas becomes more complex, traditional single-support methods struggle to meet the demands of complex engineering roadways. Therefore, the innovation of this multi-level coordinated support technology offers flexible solutions to engineering requirements. To date, combined support technology has been applied in projects such as anchor-belt-mesh-spray support, combined support using W-shaped steel bands and rock bolts, and coordinated support using hollow grout-injected rock bolts. The objective is to resolve issues like roof subsidence, inward movement of the low-bulging side walls, and support for fractured rock masses, thereby achieving surrounding rock stability.

3.3. Issues with coal mine support technology

The working face conditions in coal seam mining roadways are complex. Due to the large and irregular cross-sections of the mining roadways and the substantial thickness of the coal seam structure, roadway excavation is mostly conducted along the roof and floor of each seam. As mining depth increases, the difficulty of support technology work intensifies. Compression of the coal seam causes severe deformation, and these factors exert varying degrees of impact on support technology.

Material-wise, anchor bolts and cables exhibit insufficient strength and elongation, coupled with relatively weak impact toughness. From a technical adaptability perspective, under conditions of large deformation, high stress, and impact-induced low pressure, anchor bolts and cables are prone to fracture and failure. Furthermore, support design predominantly relies on empirical methods rather than scientific approaches. These shortcomings may lead to tunnel support failure and instability, creating significant safety hazards. Previous support technologies were not subject to stringent requirements and served mining tunnels for relatively short durations, becoming obsolete upon completion of the mining section. This necessitates substantial costs for subsequent re-supporting. Repeated anchor rod support also alters the structural stability of the tunnel working face.

4. Future trends in the innovative development of support structures

With the advancement of socio-economic development and technology, the coal mining industry has increasingly higher demands for roadway support technologies. While implementing innovative support techniques, it is essential to adhere to the principle of "three highs and one disturbance." Given the significant variations in geological conditions across different coal mines, thorough geological investigations must be conducted during roadway support implementation, and multiple methods should be employed to optimize the support structure system. Support technologies diversify to meet varying engineering requirements, encompassing anchor rods of different shapes and sizes, prestressed anchor rods, and rock bolts. Efforts must focus not only on developing intelligent support solutions but also on promoting the research and application of high-strength energy-absorbing yield anchor rods, integrated long and short rock bolts, and diversified combinations of rock bolts and U-shaped steel. Support materials will also advance toward intelligent applications. Through smart control systems that monitor changes in mine and mining roadway rock mass structures, anchor support parameters can be dynamically adjusted to enhance support effectiveness and improve mine safety. Developing intelligent mining equipment and establishing support monitoring systems will provide valuable references for mine support control technologies.

5. Conclusion

In coal mining operations, when selecting support control technologies, it is imperative to move beyond experience-based management approaches. Instead, decisions must be grounded in existing theoretical frameworks, adhering to the principle of "three highs and one disturbance" while integrating practical conditions to rationally choose support techniques. Comprehensive support technology should be the primary option, implemented according to the principles of site-specific adaptation, continuous monitoring, and all-around control. Continuously summarize issues in existing support structures, adopt a long-term perspective, and persistently update and innovate technical systems and management models. Only through such approaches can robust safety assurance be provided.

Disclosure statement

The author declares no conflict of interest.

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