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Research Progress and Discussion on Sealing Materials

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Abstract: Reducing the gas content in the coal seam can create a safer working environment for underground workers. One effective method is gas extraction and coal seam water injection. The key to this process is drilling sealing, which requires high-performance sealing materials. This paper presents an overview of commonly used sealing materials, including clay materials, cement-based materials, high water materials, and polyurethane materials. It describes the application and research status of each type of material, discusses current issues and improvements, and concludes with a look towards future developments.

Keywords: Coal seam gas; gas extraction; borehole sealing; sealing materials.

1. Introduction

Coal is a crucial energy source in China, with an extremely high annual consumption. However, the production of coal is often accompanied by the problem of coal mine accidents, with gas accidents being the most common. To prevent such disasters, coal seam water injection and gas drainage are used to reduce the coal dust and gas content [1,2]. The quality of sealing materials is crucial for gas pumping and coal bed water injection. It directly affects their effectiveness.

2. Classification of Sealing Materials

2.1. Clay Materials

In the early stages, clay sealing material is commonly used. It is derived from semi-dry clay, yellow mud, or a yellow mud-cement mixture with a fine texture and plasticity. Clay material was initially used to seal coal mine drilling holes due to its low cost, easy availability of raw materials, and simple operation. However, the high viscosity and poor fluidity of clay slurry make it ineffective in sealing fissures during actual sealing operations, which affects gas extraction during drilling. Currently, cement-based composite materials and other materials are gradually replacing clay sealing materials.

2.2. Cementitious Materials

Cement material is sourced from a wide range of sources. It exhibits strong fluidity, controllable setting time, high strength, and does not soften upon contact with water. These characteristics make it better suited to the geological environment of coal rock [3]. Cement-based materials are commonly used for sealing rock holes. Despite some shortcomings, compensatory measures have been developed to address them. This technology has become increasingly familiar and widely used. It remains one of the mainstream materials for rock hole sealing.

2.3. High Water Materials

The high water material is a novel mixed substance comprising two groups of components. When mixed with water separately, the components do not precipitate or solidify within 24 hours. After the two groups of slurry are fully mixed and stirred, a physicochemical reaction occurs, resulting in the slurry condensing and solidifying into a hard material in just 30 minutes. The material exhibits high strength in later stages and is commonly used in engineering applications, such as supporting roadways and sealing rocks [4].

2.4. Polyurethane Materials.

The sealing material used for polyurethane grouting is typically a two-component slurry consisting of black polyisocyanate and white polyol, along with catalysts, homogenising agents, and other substances. The slurry can be mixed uniformly in a 1:1 volume ratio and rapidly expands to fill, seal holes, plug water, and reinforce. It is important to note that this description is objective and avoids ornamental language. The material has several advantages, including good sealing, strong adhesion, and strong expansion. Sealing holes with this material is a simple, time-saving, and labour-saving process [5].

3. Current Status of Research on Hole Sealing Materials

3.1. Study of Clay Materials

Xu Run [6] conducted a study on cement-clay composites and found that they have good flow properties with better penetration, which can be used for general leakage plugging of fissure zones. Chen [7] and other researchers investigated the rheological properties of clay slurry after adding an accelerator. They concluded that the amount of accelerator, the duration of its application, and the material of the structural agent have an impact on the plastic strength of the modified clay slurry. Furthermore, they found that the water plugging performance and fluidity of the modified clay slurry are superior to those of cement slurry. Zhou Bin [8] conducted modification experiments on clay using Al_2O_3. The results showed that the strength of the material increased with the dosage of Al_2O_3. When 4% of Al_2O_3 was added, the strength and stability of the specimens significantly improved.

3.2. Study of Cementitious Materials

Hu Yachao [9] and other researchers have developed new sealing materials that can effectively seal blasting holes, providing an efficient solution to the difficult problem of sealing top plates. This has led to successful mechanisation of sealing holes and has yielded positive results in engineering applications. Liu Jian and other researchers have found that the addition of nano-silicon nitride alone can improve the early strength of cement. When combined with fly ash, it shows an even better synergistic effect and improves the fluidity of the cement paste, resulting in shorter initial and final setting times. Liu Jianzhong [11] and his team discovered that adding 30%-50% fly ash can significantly delay the exothermic rate of cement hydration, more so than the same ratio of slag powder. This effectively prevents cement cracking in later engineering applications. Wu Hailong [12] and his team have noted that the increase in cement hydration products is linked to an excess of $SO4^{+}$. This can have an impact on the mechanical strength of the specimen, and a continuous increase can result in an overall negative correlation with the material's strength. Zhao Yaoyao [13] and his team conducted a single-factor experimental study to regulate the size of the aluminates cement doping. They investigated the material's compressive strength, setting time, and flow propertiesand found a positive correlation between the doping of aluminates cement and the material's compressive strength and fluidity. They also found a negative correlation between the material's setting time and the material's setting.

In their study, Wang Hailiang [14] applied varying amounts of organosilane surface coating to test blocks. They discovered that a coating amount of $250g/m^2$ resulted in reduced surface pores, increased hydrophobicity, and the best protective effect. In their study, Lu Ting [15] and his team analysed the effect of doping Si_3N_4 into cement slurry as a single dosage on the basic properties of cementitious materials. They found that when 2% of nano-silicon nitride was doped, the rate of the cement hydration process was accelerated and the compressive strength of the material was improved. Liu Jian [16] and others developed a microcapsule UEA expansion agent and applied it to cement. They analysed the impact of the microcapsule UEA expansion agent on the expansion properties of cement at a microscopic level. They found that it alleviates the effect of the release of the expansion agent in cement paste. The microcapsule, which pre-protects the expansion agent, basically does not participate in the relevant reaction. However, the expansion of microcapsules is dependent on achieving certain conditions of their own strength and co-development. This application has yielded positive results due to the slow seepage of water causing expansion in the osmotic pressure of the surface layer.

3.3. Study of High Water Materials

Sun Wenbiao [17] and his team developed a new method to determine the expansion stress of hole sealing materials. They found that the expansion stress of high water materials increases with size expansion. Song Wubing [18] and his team proposed a new high water sealing material that improved gas extraction efficiency by 35%-50% and reduced usage costs. This material has been successfully applied in mines. Zhang Yinghua [19] and colleagues conducted systematic tests on the performance of high water materials. They pointed out that the material has characteristics such as high strength, fast solidification, high flow, and micro-expansion. They also found that the use of a direct hole sealing method can have a good plugging effect. Sun Wende [20] and others proposed mixing high-water materials with expanded cement and adding various admixtures for compounding. They combined this with microencapsulation technology to study the material's setting time, fluidity, and shrinkage. They found that the material coagulated and expanded simultaneously, improving its resistance to shrinkage and deformation at a later stage. Ding Yu and colleagues conducted a study on the microstructure, fluidity, coagulation time, and mechanical properties of UHW materials. They concluded that the comprehensive characteristics of UHW materials perform well, and the engineering application prospect is more open. This finding suggests that UHW materials could be a promising option for filling air-mined areas in the future. Zheng Chunshan [22] and his team developed the PD series of sealing materials. They used an environmental scanning electron microscope to study the sealing effect, material slurry penetration of the pore wall fissure state, bonding of the material and the coal wall, and compared the PD series of materials with polyurethane material. They found that the PD series of materials have a denser internal structure, which improves the negative pressure of gas extraction. Feng Guangming[23] and colleagues have developed ultra-high water materials with a water-solid ratio of up to 11:1. These materials have good flow properties and do not shrink during curing. Additionally, they allow for control over the strength and setting time of the material.

3.4. Study of Polyurethane Materials.

He Xiangxiang [24] and other researchers have found that polyurethane materials, when modified, can effectively enhance the air wedge effect of the explosive shock wave, resulting in a significant improvement in the blasting effect. Wang Leiyu [25] and colleagues have also demonstrated that polyurethane grouting materials, when modified with water glass, exhibit improved surface uniformity and reduced cracking, resulting in improved mechanical strength and reduced cost of use. Qin Xiuyun [26] adjusted the density of the polyurethane components. By increasing the density appropriately, the cytosol size of the material became smaller and the number of cytosols increased. This resulted in improved strength and uniformity, as well as enhanced thermal insulation performance and frost resistance. Xue Yaozong [27] modified polyurethane by introducing boron nitride. The modified material showed significant improvements in elongation at break, tensile strength, thermal stability, and thermal conductivity. Liu Qiang and colleagues [28] used a new type of bag-type polyurethane hole sealer in a gas concentration extraction comparison. They found that the sealer can not only seal the borehole to prevent and control gas leakage, but also facilitate later grouting, improving work efficiency. Yang Shaobin [29] and his team modified the properties of polyurethane sealing materials by adding the flame retardant trichloroethyl phosphate. They discovered that the dense internal structure of the foam was due to the addition of the flame retardant. Lu Liyuan [30] and his team investigated the injectability of polyurethane sealing material in gunhole plugging. The test revealed the presence of high temperatures during the reaction process of polyurethane sealing material, which poses certain risks. Li Ning [31] and colleagues have developed new polyurethane/polyurea reinforcement materials by compounding polyurethane materials. These materials exhibit better strength, expansion, sealing performance, and physical properties compared to traditional reinforcement materials.

4. Discussion

In China, the most commonly used material for sealing pores is still cement-based. However, the use of cement mortar filler or cement composite material mixed with several materials for direct use can no longer meet the increasing demand for pore sealing.

Many new sealing materials have complex production processes and high costs. Therefore, it is important to simplify the preparation process while ensuring good performance during large-scale production and application.

Clay materials soften easily when in contact with water. Single-component cement materials are highly susceptible to dry shrinkage, which can lead to micro-cracks. Chemical grouting materials are not environmentally friendly and can be costly. Therefore, it is important to seek out green and environmentally friendly materials.

5. Conclusion and Future Prospects

Although research on hole sealing materials has made good progress, the existing materials have not yet achieved the desired effect in actual projects. To better meet the needs of hole sealing, further research can be carried out in the following areas:

The micro-expansion property of hole-sealing materials is a crucial factor that affects the quality of hole sealing and requires further study.

The development of more affordable, durable, and recyclable materials that align with green environmental protection should be prioritised.

Future material research will focus on multi-component composite technology for hole sealing. Simple mixing of various materials is insufficient to meet the continuously growing demand for hole sealing. Therefore, new materials should be developed using multi-component composite materials, which have better grouting performance and are easy to transport and store.

Conflicts Of Interest

The authors declare that they have no conflict of interest.

References

[1] Wu Peiwu. “Analysis on effect of coal seam water injection and dust reduction by using gas drainage boreholes”, Coal Science and Technology, Vol. 42, pp. 64-66, 2021. https://doi.org/10.19896/j.cnki.mtkj.2021.06.015.

[2] Quan Hongxing. “Influence of coal seam water injection on gas desorption and release in roadway and its control mechanism”, China Coal, Vol. 47, pp. 30-37, 2021. https://doi.org/10.19880/j.cnki.ccm.2021.11.005.

[3] Chen Boyang. “Study on properties of silicon carbide/PVA/lithium sulfate composite cement sealing material”, Anhui University of Technology, 2021. https://doi.org/10.26918/d.cnki.ghngc.2021.000832.

[4] Liu Dandan. “Study on Hydrating and Hardening Mechanisms of High-Water Rapid-Setting Material”, China University of Mining and Technology, 2015.

[5] Ding Dayong. “Preparation and performance Research Of polyurethane grouting hole sealing materials”, Liaoning University of Engineering and Technology, 2017.

[6] Xu Run. Research on aggregated masses in clay and cement grout”, Coal Science and Technology, pp. 55-57, 2004. https://doi.org/10.13199/j.cst.2004.04.59.xur.018.

[7] Chen Xiaoming, Ling Xiaozhuang, Chen Qinshu. “Fundamental theoretical Research of Modified Clay Slurry”, Mining Research and Development, pp. 87-89, 2006. https://doi.org/10.13199/j.cst.2004.04.59.xur.018.

[8] Zhou bin, Gao Lei, Yu Xiangjuan. “Experimental research on nanometer alumina modified clay”, Hydrogeology Engineering Geology, Vol. 41, pp. 74-78, 2014. https://doi.org/10.16030/j.cnki.issn.1000-3665.2014.02.009.

[9] Hu Yachao, Xiong Zuqiang, Wang Chun, Wang Chen. “Research on high-efficiency sealing material and technology of coal roof deep-hole pre-splitting”, Coal Science and Technology, Vol. 51, pp. 30-36, 2023. https://doi.org/10.13199/j.cnki.cst.2021-0357.

[10] Liu Jian, Tang Tiantian, Lu Ting, Ji Xiaoli, Qian Liang. “Activation effect of the fly ash with nano silicon nitrideon the early strength properties of the minung-left cement sealing materials”, Journal of Safety and Environment, Vol. 20, pp. 1752-1757, 2020. https://doi.org/10.13637/j.issn.1009-6094.2019.1236.

[11] Liu Jianzhong, Sun Wei, Mu Changwen, Liu Jiaping. “Research on the Hydration Heat of Paste in UltraHigh Strength Concrete at Low Water-Binder Ratio”, Journal of Building Materials, Vol. 13, pp. 139-142, 2010.

[12] Wu Hailong, Liu Jian, Ji Xiaoli, Guo Linjie, Lou Yabei. “Study on influence to early strength performance of hole sealing cement used in coal mine by new lithium sulfate compound early strength agent”, China Safety Production Science and Technology, Vol. 10, pp. 34-38, 2014.

[13] Zhao Yaoyao, Sun Yuning, Wang Zhiming. “Mixed volume of aluminous cement affected to grouting material performances of borehole sealincfor gas drainag”, China Safety Production Science and Technology, Vol. 10, pp. 34-38, 2014. https://doi.org/10.13199/j.cnki.cst.2018.04.025.

[14] Wang Hailiang, Li Yizhen, Rong Hui. “Effect on Protective Performance of Organosilicone Protective Agent for Aluminate Cement Mortar”, Journal of Building Materials, Vol. 22, pp. 516-522, 2019.

[15] Liu Ting. “Study on early strength performance of sealing material for activated fly ash/cement composite mine”, Anhui University of Technology, 2019.

[16] Liu Jian, Liu Zegong, Wu Hailong, Li Chongqing. “Study on effect of microcapsule coating expansion agent on expansion property of hole sealing cement in coal mine”, China Safety Production Science and Technology, Vol. 11, pp. 45-50, 2015.

[17] Sun Wenbiao,Guo Bingbing,Zhang Ruilin “Experimental Study on Expansion Stress of High-water-content Material Type Sealing Material foiGas Drainage Boreholes”, Coal Technology, Vol. 41, pp. 82-85, 2022. https://doi.org/10.13301/j.cnki.ct.2022.05.021.

[18] Song Wubing, Lin Boquan, Hao Zhiyong, Sun Weihao. “Research and Application of New High Water Material Sealing Performance in Gas Drainage Borehole”, Coal Engineering, Vol. 47, pp. 94-96, 2015.

[19] Zhang Yinghua, Liang Tongzhu, Cui Jingkun. “Applied research on the sealing technology of injection in "weak seam, roof and floor" for dustcontrol with high-water rapid-solidifying material”, Coal Journal, pp. 46-49, 2003.

[20] Sun Wende, Li Ziquan, Zhou Jun, Lin Chuanbing. “Research on New Borehole Sealing Material and Sealing Technique Applied to Mine Gas Drainage”, Coal Science and Technology, Vol. 40, pp. 60-63, 2012. https://doi.org/10.13199/j.cst.2012.04.65.sunwd.020.

[21] Ding Yu, Feng Guangming, Wang Chengzhen. “Experimental research on basic properties of superhigh-water packing material”, Journal of Coal, Vol. 36, pp. 1087-1092, 2011. https://doi.org/10.13225/j.cnki.jccs.2011.07.027.

[22] Zheng Chunshan, Lin Boquan, Yang Wei. “Study on Performances Test of High Tightnessn Borehole Sealing Material for Gas Drainage Borehole”, Coal Engineering, pp. 88-90+94, 2012.

[23] Feng Guangming, Wang Chengzhen, Li Fengka. “Research on Bag-Type Filling Mining with Super-High-Water Material”, Journal of Mining and Safety Engineering, Vol. 28, pp. 602-607+613, 2011.

[24] He Xiangxiang, Chen Dongliang, Jiang Weifeng. “Modification and Property Analysis of Polyurethane Blast Hole Plugging Material”, Plastics, Vol. 51, pp. 16-20, 2022.

[25] Wang Leiyu, Shao Xiaomei, Hu Jingyu. “Preparation and properties of polyurethane grouting materials modified by waterglass”, South-toNorth Water Transfers and Water Science & Technology, Vol. 21, pp. 1152-1158, 2023. https://doi.org/10.13476/j.cnki.nsbdqk.2023.0113.

[26] Qin Xiuyun. “Preparation and properties of polyurethane polymergrouting materials”, Functional Materials, Vol. 54, pp. 11134-11138, 2022.

[27] Xue Yaozong, Zhao Yujin, Wu Shuying. “Preparation and characterization of modified boron nitride/waterborne polyurethane thermaconductive composites”, New materials in chemical industry, 2023. http://kns.cnki.net/kcms/detail/11.2357.TQ.20231211.0939.007.html.

[28] Liu Qiang, Zhang Yachao, Wang Xiaojun. “Application of Bag Polyurethane Sealing Device in Soft Coal Seam”, Coal Technology, Vol. 38, pp. 79-81, 2019. https://doi.org/10.13301/j.cnki.ct.2019.12.028.

[29] Yang Shaobin, Wang Yang, Dong Wei. “Preparation and Properties of Polyurethane Gas Sealing Materia”, China Plastics, Vol. 28, pp. 55-58, 2014. https://doi.org/10.19491/j.issn.1001-9278.2014.02.010.

[30] Lu Liyuan, Wang Xiaoyun, Zhao Xianying. “Study on Application of Polyurethane Foaming Material in Blast-hole Stemming”, Blasting, Vol. 35, pp. 142-146, 2018.

[31] Li Ning, Zhao Qingxiang, Zhang Junbo. “A new type of polyurethane polyurea reinforcement material for coal mine”, Modern Chemical Industry, Vol. 36, pp.126-128, 2016. https://doi.org/10.16606/j.cnki.issn0253-4320.2016.10.031.