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R&D of colloid components of composite material for fire prevention and extinguishing and an investigation of its performance

Zhian Huang^{a,b}, Chuanwu Sun^a, Yukun Gao^{a,*}, Yucheng Ji^a, Hui Wang^a, Yinghua Zhang^a, Rui Yang^a

^a State Key Laboratory of High-Efficient Mining and Safety of Metal Mines (University of Science and Technology Beijing), Ministry of Education, Beijing 100083, China

^b Work Safety Key Lab on Prevention and Control of Gas and Roof Disasters for Southern Coal Mines (Hunan University of Science and Technology), Xiangtan, Hunan 411201, China

ARTICLE INFO

Article history:

Received 27 June 2017

Received in revised form 18 October 2017

Accepted 4 November 2017

Available online 17 November 2017

Keywords:

Compound material
Spontaneous combustion
Colloid components
Choosing experiment
Orthogonal experiment
Optimal proportion

ABSTRACT

Because the existing fire prevention and extinguishing materials for coal mining cannot adhere to coal for long periods of time, this study investigated their colloid components. A colloid recipe of sodium silicate as the base material, sodium bicarbonate as the coagulation accelerator and sodium polyacrylate as the polymer additive was determined. An optimum proportion was obtained by orthogonal tests, whereby the ratio of water to solid was 4:1, sodium silicate accounted for 4%, sodium bicarbonate accounted for 5% and sodium polyacrylate accounted for 0.75%. Comparing the performance of four other typical materials of fire prevention and extinguishing through contrast experiments, we observed that the new material has advantages of dropping the temperature, lowering the concentration of oxygen and carbon monoxide and increasing the concentration of carbon dioxide. In addition, a field test was conducted with the new material. After injection, three zones of spontaneous combustion showed clear changes: the oxidation temperature rise zone was ahead by 8 m, its length was shortened by 20 m and the choking zone moved up by 28 m. These changes indicated the improvement of colloid could significantly increase the effect of fire prevention and extinguishing materials.

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1. Introduction

As an application of a fully mechanized top-coal caving method with high yield and efficiency at ultra-thick coal seams, mines that are away from spontaneous combustion before catch fire of spontaneous combustion frequently for the increase of mining intensity, expansion of goaf and more complex ventilation system (Mayala et al., 2016; Zhou et al., 2013a). Statistical analysis of the existing accident data in China showed that fires caused by spontaneous combustion in coal seams are particularly serious, accounting for over 90% of the total mine fire accidents (Martin et al., 2016; Qin et al., 2016; Yilmaz and Uslu, 2007).

Currently, in the study of fire prevention and extinguishing techniques for mines, there are three main methods to prevent spontaneous combustion of seams. The first is to isolate coal from oxygen, preventing spontaneous combustion due to the lack of oxygen; the second is dropping the temperature of coal to slow the oxidation of coal and make the heat harder to gather, therefore keeping the coal from spontaneous combustion; and the last is to let the active structure on the coal surface inert to reduce the speed of coal-oxygen recombination and inhibit the oxidation of coal, effectively stopping spontaneous combustion (Beamish et al., 2001; Benfell et al., 1999; Chen et al., 2016a; Mohalik et al., 2009a; Zhang et al., 2016a,b; Deng et al., 2016). Recently,

* Corresponding author.

E-mail address: gaoyukunustb@126.com (Y. Gao).

<https://doi.org/10.1016/j.psep.2017.11.004>

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researchers at home and abroad have proposed many new technologies to prevent spontaneous combustion based on inerting, cooling and blocking of air leakage or a combination of these techniques (Kim et al., 2015; Lu, 2009; Oparin et al., 2016; Singh, 2013; Xia et al., 2016).

At present, the most commonly used materials for fire prevention and extinguishing include yellow muds (Cao et al., 2012; Colaizzi, 2004), inhibitors (Liu and Wu, 2010; Pandey et al., 2015), inert gases (Takahashi et al., 2011; Zhou et al., 2015), anti-heat gels with high water (Wang et al., 2016) and three-phase foam (Shao et al., 2015; Shi et al., 2015; Zhou et al., 2006). These materials have different advantages in the performance of fire prevention and extinguishing but also have insufficiencies (Binkau et al., 2015; Bogdanova et al., 2016; Ray and Singh, 2007). Grouting for fire prevention and extinguishing has a high engineering quality, and the slurry is hard to solidify, which worsens the work environment. The mud concentrates at lower terrains in the goaf area, not playing a role in packaging for top-coal and coal pillars (Deng et al., 2016; Poluboyarov et al., 2009; Ren et al., 2016; Zhou et al., 2013b) due to its high flowing capability. The inhibitor is hard to distribute uniformly on the coal surface, requiring a complex spraying technique, and the dry inhibitor even has a catalytic effect, speeding the process of spontaneous combustion (Pone et al., 2007; Qi et al., 2016). Inert gas is prone to diffusion with wind, requiring strict blockade of air leakage, it has a long extinguishing cycle, it is not easy to stay in the goaf and it cannot drop the coal temperature (De Rosa and Litton, 2007; Mohalik et al., 2009b; Niu and Wang, 2011). Anti-heat gels with high water do not offer enough bonding strength and tend to dehydrate when injected to the high ignition point. Finally, coagulation accelerators have a pungent smell, polluting the working environment, and it is expensive (Chen et al., 2016b; Guo et al., 2014). The stability of three-phase foam is susceptible to the property of soil and temperature (Lee et al., 2014; Lu et al., 2015; Zhang and Qin, 2016; Zhang et al., 2016c).

Expanding on the advantages and shortcomings of the existing fire prevention and extinguishing materials, this paper does further research on the compound material of fire prevention and extinguishing in coal mines. The material is a mixture containing inert gas, loess, gel and other auxiliary additives, of which the colloid component makes the compound material obtain better properties of water holding, cooling, flowing and solidifying. The colloid is mainly applied to enhance the activity of substance (Pawlowska et al., 2017) and change the fluidity of material (Zhang et al., 2012). However, there are not too many applications in fire prevention of coalmine. Deng et al., 2015 studied the colloid of flyash on fire prevention under mines. So in general, the research on colloid component of composite material for fire prevention is not really enough. In order to significantly improve its performance in fire prevention and extinguishing, this article makes a further effort to study the composition of and performance of gels and conduct field tests as well.

The gel of the compound material of fire prevention and extinguishing is composed of base material, coagulation accelerator, polymer additives and water. With the help of gelatinizer, coagulation accelerator and other auxiliaries, the colloid, which is a dispersion system that uniformly distributes inert gas, is formed after a series of physical reactions. During the chemical reaction to produce the colloid component, the colloid is a transparent solution with fine fluidity and a similar viscosity to water before finally forming. After formation, it turns turbid, completely loses fluidity and is prone to accumulate. In view of the cost, safety and environmental protection and simplicity of the technique, the colloid component of the composite fire prevention and extinguishing material is reasonably compounded to overcome the insufficiency that its performance is not comprehensive. Contrast experiments between the newly developed fire prevention and extinguishing material and four other typical materials were carried on in the laboratory; we also performed a field test at 80,704 working face in the Yangquan Coal Group to prove its fire prevention and extinguishing performance (Beaumont et al., 2012; Qi and Chen, 2009; Zhai et al., 2011) by analyzing the variety of the “three zones” of spontaneous combustion and concentration of gases inside the goaf. The results provide evidence of control of spontaneous combustion of the remaining coal underground with effective and reliable materials, technical devices

and solutions, ensuring the safety of mine production and improving the production efficiency and economic benefits.

2. Experiment

2.1. Colloid component selection and compound

2.1.1. Colloid component selection

Many materials could be used as gel components of the composite fire prevention and extinguishing material; however, not all are suitable for the control of spontaneous combustion of coal seams. With consideration of features of coal mine fires, the fire prevention and extinguishing materials used in mines must have the following properties: fine permeability to enter inside of loose coal, taking the effect of plugging and inhibition, to prevent the coal from reigniting due to secondary oxidation; good resistance with heat to avoid vaporizing at high temperature and fully play the function of cooling; no pollution to the environment, corrosion to underground devices, harm or poison; low cost and simple gelling technique for easy field application. We must choose materials of colloid components proper for fire prevention and extinguishing of coal seams according to the above requirements.

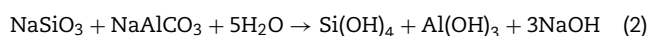
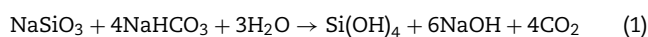
(1) Choosing of base material

Currently, the gel injection method used in coal mines for fire prevention and extinguishing usually applies sodium silicate, a kind of inorganic material, as a gelatinizer and ammonium salt and sodium salt as crosslinking agents. This kind of colloid component is a synthetic hydrogel formed by chemical crosslinking, and its performance in fire prevention and extinguishing is excellent. It is not only cheap and is widely available, but it also is a good inhibitor that enhances the performance of fire prevention and extinguishing of colloid component and has a better gelling performance.

(2) Choosing of coagulation accelerator

At present, research has suggested that sodium meta-aluminate and bicarbonate are used as coagulation accelerators. According to the study of Gao et al. (2012), sodium bicarbonate, potassium bicarbonate and ammonium bicarbonate have the best inhibition performance of all commonly used bicarbonates. Because ammonium bicarbonate produces a pungent gas, it will not be used for environmental protection. In terms of price, sodium bicarbonate is 2680 yuan per ton, while potassium bicarbonate is 6800 yuan per ton. Having a comprehensive view of all factors, this paper selected sodium bicarbonate as a coagulation accelerator, and the final one will be chosen between sodium bicarbonate and sodium meta-aluminate.

The following equations are reaction equations of sodium silicate with sodium bicarbonate and sodium aluminate, respectively.



According to the equations, the main material of colloid component produced by water and sodium bicarbonate is Si(OH)_4 , whereas in the reaction of water and meta-aluminate, the major materials are Si(OH)_4 and Al(OH)_3 . Therefore, the

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