Advanced Powder Technology 27 (2016) 1645–1650

Contents lists available at ScienceDirect

Advanced Powder Technology

journal homepage: www.elsevier.com/locate/apt

Original Research Paper

The application of ultra-fine fly ash in the seal coating for the wall of underground coal mine

Huiping Song *, Jianqiang Liu, Fangbin Xue, Fangqin Cheng

State Environment Protection Key Laboratory of Efficient Utilization Technology of Coal Waste Resources, Institute of Resources and Environmental Engineering, Shanxi University, Taiyuan 030006, China

ARTICLE INFO

Article history:
Received 13 July 2015
Received in revised form 29 March 2016
Accepted 27 May 2016
Available online 4 June 2016

Keywords:
Ultra-fine fly ash (UFA)
Seal coating
Underground coal mine
Air tightness

ABSTRACT

To meet the particular safety requirements for underground coal mining, this paper proposes is going to investigate the capability of ultra-fine fly ash (UFA) with styrene-acrylic emulsion to improve safety for underground mine workers. After studying on the influence of different percentages of UFA on the comprehensive property of seal coating, the optimal amount of UFA is determined as 60%. The water absorption of the seal coating after 7 d is 5.0%. Its original tensile strength is 3.09 MPa. The elongation at break is 80%, and the bonding strength is 0.72 MPa (7 d) and 1.08 MPa (14 d), up to the level II standard of GB/T23445-2009 polymer cement water proof coating. The flame retardant property and antistatic property is up to the safety standard for gas-sealing materials of underground coal mine of MT113-1995. Scanning electron microscopy and air tightness tests show that this material has a compact pore structure with good air tightness, and can be used as gas seal coating for underground coal mine.

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1. Introduction

Coal is used as the major energy source in China for a long time, and will remain so in the next few decades. Major accidents occur from time to time during coal mining, with the gas accident on the top of the list, causing severe damage and loss. Sealing materials are categorized into organics and inorganics. Inorganic mineral materials are cheap, non-toxic and harmless. However, weak tenacity and being easy to break make them less applicable [1]. Organic grouting materials such as polyurethanes and epoxy resin, are able to fill the fine pores and cracks in soil [2,3] but they are unstable when used in the wall of underground coal mine. In addition, chemical grouting materials have weak flame-retardant property and can cause pollution to the underground water system [4,5]. Thus, it is necessary to develop gas-sealing materials for the underground coal mining, which have good air tightness and that are cheap and environment friendly.

The chemical components of fly ash discharged from thermal power plants include SiO_2 and Al_2O_3 in glass and crystalline phase, with the crystalline components as mullite and quartz [6]. Because of morphological effect, pozzolanic effect and micro-aggregate effect, fly ash is normally used as mineral admixture in cement and concrete [7,8]. Some effort has been made to develop gas sealing materials with fly ash as filler [9,10]. Although the fly ash sealing material can prevent gas leaking to a certain degree when used for underground coal mine, there is enough room that the sealing effect need to be improved.

To optimize the sealing effect, only a small amount of fly ash is required, because the high volume of fly ash may affect the crystallization and slow down the pozzolanic reaction [11]. To have the best performance of this sealing material, the most effective approach is to grind fly ash into ultra-fine powder. UFA is produced by a proprietary separation system with a mean particle diameter of 1–5 μm [12].

As fly ash becomes ultrafine powder, it is beneficial in reducing the harm of residual carbon and minimizing the variability of constituents in typical fly ash [13]. The finer particle size, therefore, improves the morphology, mineralogy and chemical composition of materials [14]. UFA is suitable as filler, and it is easily dissolved and accelerated the pozzolanic reaction to improve the strength characteristics, and possesses better suspension property and dispersibility, etc. [15].

This paper investigated using UFA as filler together with styrene-acrylic emulsion and other functional additives to develop new seal material for the underground coal mine. To optimize the sealing effect, cement was replaced by fly ash in different proportion to investigate the apparent property, mechanical property, air tightness and micro-structure of the coating, as well as the hydration products of binding materials. The flame retardant property

* Corresponding author.
E-mail address: songhp@sxu.edu.cn (H. Song).

http://dx.doi.org/10.1016/j.apt.2016.05.028
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and antistatic property were also studied. The result will provide practical guide for the application of UFA in the seal coating of the underground coal mine.

2. Materials and methods

2.1. Materials

Styrene-acrylic emulsion S400F (Basf Company); UFA (Shanxi Huatong Company); Portland cement (325#, Taiyuan Cement Company); Aluminum hydroxide (Analytical reagent, Tianjin Guangfu), Antimonous oxide (Sb_2O_3, Analytical reagent, Tianjin Guangfu), 70# chlorinated paraffin (Analytical reagent, Tianjin Guangfu), Zinc borate (Analytical reagent, Tianjin Guangfu), graphite (Analytical reagent, Tianjin Guangfu), Conductive carbon black (Analytical reagent, Tianjin Guangfu).

2.2. Experimental method

Standard preparation condition: temperature 23 ± 2 °C, relative humidity 45–70%. Water was added to the styrene-acrylic emulsion. After well-mixed with a glass rod, the emulsion was mixed in a disperser (KS-370, Shanghai) for 1 min. Subsequently, solid powder that was already well-mixed was added and mixed up by a glass rod. The viscosity of mixture was monitored by a digital viscometer (STM-IVB, Shanghai), and was maintained within 75–82 KU by (adding water), and then the admixture were stirred by disperser at 600 r/min for 5 min. After sitting for 2 min, the mixed coating materials were poured into a template, aging for 7 d and ready for using.

2.3. Characterization method

The size and distribution of the sample were measured by the Particle Size Analyser (Eyetech/CIS, Ankersmid B.V., Holland). The appearance of UFA was observed by SEM (S-4800, Hitachi, Japan). GB/T176-96 method was adopted to test the ignition loss of UFA. The surface drying time and full drying time of the coating were recorded in reference to the international standard GB/T16777-2008. After the coating was dried, the bonding strength was measured by a SW-6000C bond strength tester with high precision. The tensile strength of the material was determined by an electron tensile tester (DL5000, Jianyi, Tianjin). The phase composition of the material was analyzed by XRD (D2 PHASER, Bruker, Germany). American standard ASTM-D471 was used to evaluate the 7 d water absorption of the material. Static electricity resistance was measured in accordance with the coal industry standard MT113-1995 by surface resistance tester (EMI-20780, DESCO, USA). The flame-retardant property of the material was assessed by an alcohol lamp and an alcohol blast burner with reference to GB/T7755-2003. A gas permeation meter (VAC-V1, Languang, Jinan) was used to determine the air permeation (R, cm^3/m^2 24 h 0.1 MPa) by differential pressure method. The permeability coefficient (Q, cm^3 cm/m^2 s cmHg) was calculated by $Q = R \times L$, where L representing the thickness of the material, and in this thesis, it was 3.3 mm.

In this paper, each experiment was repeated three times, and the average value was as the experimental result.

3. Results and discussion

3.1. UFA analysis

The ignition loss of UFA used in this study was 7.92%, up to level II standard of the national standard GB1596-2005 (ignition loss $\leqslant$ 8.0%), so the UFA was directly used as powdery filler. The particle size analysis of UFA was shown in Fig. 1. The average size of UFA used in this study was around 2.2 μm. The particle size distribution was narrow, with over 80% particles within the 3 μm range. The appearance of ultra-fine powder was observed through SEM (Fig. 2). Most particles with homogeneous size were round and smooth in surface with good dispersibility. Ultra-fine powder together with other particles could form good gradation and improve the liquidity of binding materials, which was helpful to the filling and thinning of pores in coating materials [16].

3.2. The effects of different amounts of UFA on the mechanical property

3.2.1. Comparison of apparent property of the coating

At the fixed amount of 50 g emulsion, and 80 g UFA and cement in total, 5 g chlorcosane, 3 g aluminum hydroxide, 4 g zinc borate, 3 g antimonous oxide, 3 g graphite, 2 g conductive black, the apparent coating properties with varied ratio of UFA to cement were shown in Table 1. As the amount of UFA increased, the coating required more water, with the bonding strength also increased. As the filler particles became smaller, the surface area increased, that could considerably increase the viscosity of mixture [17].

When the proportion of UFA was in the range of 20–60%, the coating displayed a good apparent property. When UFA exceeded 70%, the water demand of the coating further increased. After the

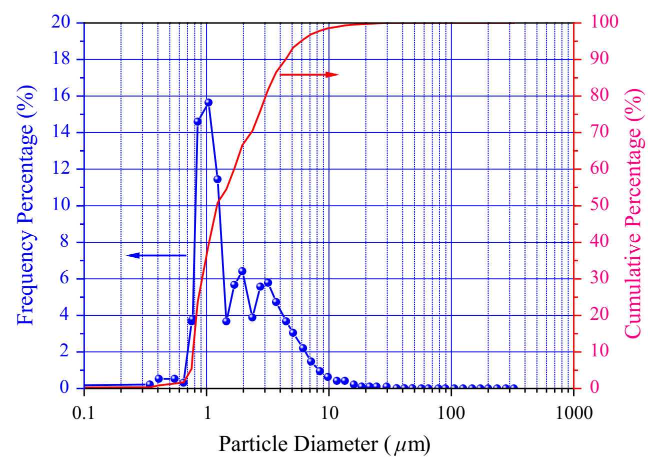

Fig. 1. Analysis of particle size of UFA.

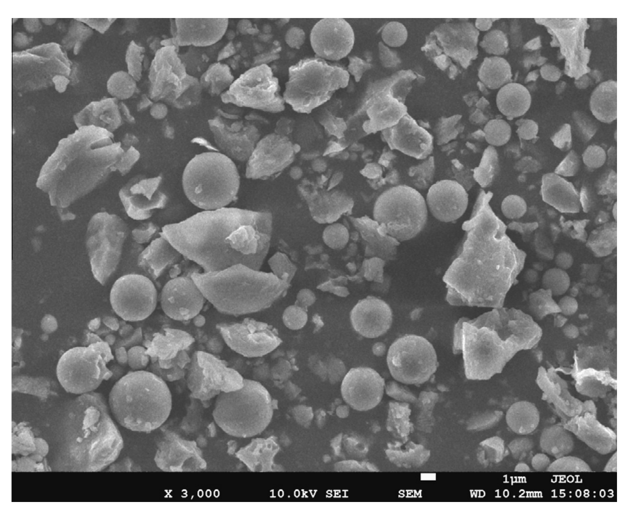

Fig. 2. SEM picture of UFA.

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