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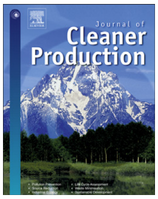

A concrete material with waste coal gangue and fly ash used for farmland drainage in high groundwater level areas

Jinman Wang [a, b, *], Qian Qin [a], Sijia Hu [a], Kening Wu [a, b]

[a] *College of Land Science and Technology, China University of Geosciences, 29 Xueyuanlu, Haidian District, 100083 Beijing, People's Republic of China*

[b] *Key Laboratory of Land Consolidation and Rehabilitation, Ministry of Land and Resources, 100035 Beijing, People's Republic of China*

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ABSTRACT

Because farmland drainage is difficult in coal mining subsidence areas with high groundwater level and the utilization rate of mine solid wastes (including coal gangue and fly ash) is low, this paper predominately discusses the permeability of the concretes composed of coal gangue and fly ash when applied in farmland drainage ditches. In this study, two experiments were designed. One experiment investigated the permeability and compressive strength of the concrete that used waste coal gangue and fly ash. The experiment consisted of five mixes: using waste coal gangue to replace 25% and 15% of the gravel, using fly ash to replace 10% and 15% of the ordinary Portland cement, and a blank control. The other experiment investigated the permeable rate of an indoor simulation drainage ditch lined with the material that had the mixing proportion of mix V from experiment one; this mixing proportion was found to have the largest permeability coefficient and also satisfied the compressive strength standard. The results of this study indicate that the concrete using waste coal gangue and fly ash had better water permeability than ordinary concrete. The concrete in this study had a high subsurface drainage modulus, making it feasible for application in coal mining subsidence areas with high groundwater levels. Moreover, partial replacement of ordinary Portland cement by fly ash and coarse aggregate by coal gangue can alleviate environmental problems.

1. Introduction

China has the largest coal mining subsidence area in the world. The subsidence land area is currently 700,000 km^2 and is continually increasing at a rate of 130 km^2 every year. Coal mining results in substantial ecological and environmental problems, such as lifting the groundwater level and causing soil salinization (Shepley et al., 2008; Wu et al., 2009; Zhang et al., 2008). Farmland drainage is a difficult problem that must be urgently solved in coal mining subsidence areas with high groundwater levels. The soil drainage ditches are not stable because of the high groundwater level, which results in a larger size required for the drainage ditch and more land occupation. In addition, because the side slope material of the traditional concrete used in farmland drainage ditches is dense, this concrete often fails to achieve good performances during subsurface drainage.

Substantial mining solid wastes are generated during coal mining (Qi and Yuan, 2013). The output of coal gangue and fly ash was 1.07 billion tons in China in 2010; this output is expected to reach approximately 1.3 billion tons by the end of 2015 because of the developing electric power industry. If this large quantity of coal gangue and fly ash is not effectively disposed, then these materials will cause dust, air pollution and the destruction of the ecological environment (Nathan et al., 1999; Prasad et al., 1996; Xu et al., 2009). Currently, coal gangue is primarily utilized in the following aspects: power generation, agricultural fertilizer, highway roadbeds, mined land reclamation backfill, brick production, cement production, and concrete production (Hao and Wang, 2009; Liu and Liu, 2010; Yu et al., 2012). Fly ash has been utilized in the following applications: agricultural soil amelioration agent, glass and ceramics manufacturing, zeolite production, mesoporous materials formation, building material production, geopolymer synthesis, catalysts and catalyst supports, gases and waste water absorbents, and metal extraction (Ahmaruzzaman, 2010; Blissett

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* Corresponding author. College of Land Science and Technology, China University of Geosciences, 29 Xueyuanlu, Haidian District, 100083 Beijing, People's Republic of China.

E-mail address: wangjinman2002@163.com (J. Wang).

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and Rowson, 2012; Carrasco et al., 2014). Although the utilization of coal gangue and fly ash is diverse, the utilization rate remains low because of the large quantities involved, e.g., the utilization rate was only 27% in 2013 in China (He et al., 2012).

Farmland drainage ditches are an indispensable part of the agricultural landscape and have important ecological functions and ecological effects (Cooper et al.; Herzon and Helenius, 2008). To date, fewer studies have investigated the concrete material of farmland drainage ditches, whereas numerous studies have focused on vegetated farmland drainage ditches (Denton et al., 2006; Moore et al., 2001). Previous studies indicated that vegetated drainage ditches provide good retention and adsorption of pesticides and other toxic substances and reduce the harm to the downstream environment (Bennett et al., 2005; Cooper et al., 2004; Werner et al., 2010). In addition, different plants have unique effects on absorbing harmful substances (Rogers and Stringfellow, 2009). Vegetated ditches can abate 50% of the total N load per kilometer and have a better effect than unvegetated ditches (Pierobon et al., 2013). These vegetated drainage ditches have a good adsorption capability; however, vegetated ditches affect drainage because of the increased roughness coefficient from the vegetation.

Some general solid waste materials have been widely in concrete materials, including crushed glass (de Castro and de Brito, 2013), copper slag (Thomas et al., 2013), tire rubber (Su et al., 2015; Thomas et al., 2014a), clay brick (Zong et al., 2014), marble slurry (Rana et al., 2015), and so on. These concrete materials show good strength, durability or permeability. The use of fly ash and coal as a partial replacement for cement and coarse aggregate in concrete has numerous benefits: reduced greenhouse gas emissions, good long-term strength, reduced energy consumption, and reduced pressure on natural resources. Moreover, fly ash and coal gangue are economical, and there are numerous fly ash and coal gangue resources (Ahmaruzzaman, 2010).

To solve the drainage problem in mining subsidence areas with high groundwater levels and to improve the utilization rate of coal gangue and fly ash, the goals of this study were 1) to investigate the use of fly ash and coal gangue as alternative materials for use in the production of concrete that can be applied to permeable drainage ditches and 2) to select an optimal mix proportion of such a concrete through a permeability experiment and a simulation drainage experiment.

2. Materials and methods

2.1. Materials

2.1.1. Cement

The cement used in the experiments was P·II ordinary Portland cement (OPC) (China Building Industry Association, 2007) produced by Hebei Cement Limited Company, having 3-, 7- and 28-day compressive strengths of 25, 32 and 45 MPa, respectively. The specific gravity and blaine specific surface area of the cement were 3.12 and 3490 $cm^2\ g^{-1}$, respectively.

2.1.2. Aggregates

The coarse aggregate was gravel with a fineness modulus of 5.96 and a continuous gradation, with the gradation in the range from 5 to 15 mm. The coarse aggregate was completely dry, with a negligible amount of mud. To ensure the strength of the porous concrete, yellow sand and medium sand were used as the fine aggregate, with a fineness modulus of 3.21 and 2.58, respectively. The physical properties of aggregates are presented in Table 1, and the particle size distributions of aggregates are shown in Fig. 1.

2.1.3. Fly ash

The waste fly ash was supplied by the Jiawang Power Plant in the Xuzhou city of Jiangsu Province, with a water absorption content of 0.95% and a bulk density of 2.2 $t\ m^{-3}$. The fineness, the remaining percentage passing through a 45-um sieve, is 10.9% (<12%, grade I). The particle morphology was a porous glass structure with a cenosphere of 10–100 um.

The samples of fly ash were digested by the full decomposition method with hydrochloric acid, nitric acid, hydrofluoric acid, and perchloric acid. Cu, Zn, Ni, and Cr were determined using flame atomic absorption spectrophotometry, Pb and Cd were determined using the F-ass method, Hg was determined using cold vapor atomic absorption spectrometry, and As was determined using the diethyl dithiocarbamate sliver spectrophotometry method. The contents of Cd, Hg, As, Pb, Cr, Cu, Zn, Mo and Ni were measured using an atomic absorption spectrophotometer (the Shimadzu AA-6601F type), and the contents are presented in Table 2.

2.1.4. Coal gangue

The waste coal gangue was supplied from the Jiawang mining area in Xuzhou, Jiangsu Province. The mineral composition of coal gangue is dominated by kaolinite. Kaolinite mainly was present as flakes of scaly morphology with a partial wormlike structure. The coal gangue was not spontaneously combustible. Before use, coal gangue was crushed and washed to remove the dust. Next, after drying, they were sieved with a 30-mm sieve. The levels of the trace elements As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn in coal gangue were determined. The powdered coal gangue samples were digested using an acidic solution ($HCl:HNO_3:HF$: 3:3:2) in a microwave oven in a Teflon beaker at 120 °C maintained for 20 min, followed by 180 °C for 25 min. The rest of the HF was neutralized with HBO_3. After digestion, the solution was filtered through a 0.45-μm filtering membrane and quantified to a final 25-ml solution with 3 wt.% HNO_3 for subsequent analysis. The contents of the environmentally sensitive trace elements in coal gangue were measured using ICP-MS, except for Hg, which was determined using cold vapor atomic absorption spectrometry. The physical properties of the crushed coal gangue are presented in Table 1, and the trace elements in coal gangue are presented in Table 2.

2.1.5. High-range water-reducing admixture

The high-range water-reducing admixture is the essential component of the concrete, which ensures that the concrete is able to flow under its own mass. The AE-d naphthalene superplasticizer was used in the experiments to enhance the workability and water retention of the concrete. The main performance indices of this water-reducing admixture are presented in Table 3.

2.2. The experiments for determining the permeability coefficient and the compressive strength of the concrete

2.2.1. Experimental device

The device used to measure the water permeability coefficient is shown in Fig. 2. The device is composed of three parts: a Marriotte bottle, an impervious cylindrical sleeve and the pedestal. On one side of the Marriotte bottle, an outlet with a diameter of 10 mm is connected to the impervious cylindrical sleeve. The impervious cylindrical sleeve is a straight cylinder with a height of 250 mm and a diameter of 150 mm; the top and bottom of the sleeve are unclosed. On one side of the cylinder, an outlet with a diameter of 10 mm is positioned 180 mm away from the bottom and is linked with the Marriotte bottle. A 100-mm high closed concrete block was placed at the bottom of the sleeve to allow water to permeate through the block. The pedestal (a permeable cylindrical sleeve

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