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Preparation and characterization of permeable bricks from gangue and tailings

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HIGHLIGHTS

- New permeable bricks were prepared by using gangue and tailings.
- Effects of adding new aggregate and sintering temperature were investigated.
- Effects of aggregates content and aggregates size were also investigated.
- Fabrication was simplified without using natural clay and artificial aggregates.

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ABSTRACT

Gangue and tailings are both solid wastes produced by mining processing. In this study, permeable bricks were prepared by partial sintering of aggregates method, using gangue and tailings as aggregates and binder, respectively. The effects of aggregates content, aggregates size, sintering temperature and adding new aggregate on the permeability, apparent porosity, water absorption and mechanical properties of the prepared permeable bricks were systematically investigated. The optimum parameters to prepare the permeable bricks were obtained at 1180–1200 °C for 45 min with 20 wt% tailings, 60–70 wt% gangue and 10–20 wt% waste ceramic. The prepared permeable bricks, with the optimized parameters, have a high permeability (about 0.03 cm/s), exhibiting considerable compressive strength (exceeding 30 MPa). Combined with the macroscopic properties and microstructure analysis of the permeable bricks, the variation of the performance of permeable brick under different factors is studied. The preparation of permeable bricks using gangue and tailings may provide a promising way to reuse mine solid wastes, considering the advantages in both economic and environmental aspects.

1. Introduction

The notion of "sponge city" [1–3], which is an urban rain flood management concept, has attracted more and more attention in China. It rests on the notion that the city can respond to natural flood disasters with good flexibility. The conventional concrete road pavement is impervious and it increases stormwater runoff, accumulating a large amount of water during storms. To solve the resulting urban flooding problems, it is critical to use permeable bricks for the construction of pavements.

With open pores and channels in the compacted block, permeable brick allows rainwater to penetrate through to the soil. The filtered stormwater is then either harvested for later reuse or released slowly into the underlying soil or drainage system. Therefore, the application of permeable bricks can reduce surface stormwater runoff and increase groundwater recharge. With so many advantages, permeable bricks have been widely used in residential sidewalks, pavements, parking lots and pedestrian areas. Many literatures [4–6] have demonstrated the excellent performance of permeable bricks in urban stormwater management systems.

Currently, there are mainly two kinds of permeable bricks: cementitious bricks and sintered bricks [7,8]. The former are primarily cement bonded materials without sintering process [9,10], and the latter are fabricated by partial sintering of aggregates, even adding pore forming agents [11]. Cementitious bricks have a disadvantage of low production efficiency for their essential curing process (may take as long as 28 days). On the contrary, sintered permeable bricks not only have a high production rate, but also

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have a better appearance and higher compressive strength. And for permeable bricks, compressive strength and permeability are two most important performance parameters.

With the increasingly widespread use of permeable bricks, many scholars began to carry out related researches, several kinds of solid waste have been used to produce permeable bricks, such as molten slag [12], bottom/fly ash [13], municipal waste incineration bottom ash [14]and waterworks sludge [15]. However, the above-mentioned methods [12,13] often involve a critical step in producing artificial aggregate, which consumes extra energy. In the meantime, natural clay is always added as a binder during the sintering process [11,16], which is a non-renewable resource. In order to protect natural clay resources and develop environmentally friendly building materials, some countries such as China have begun to prohibit the production and use of clay bricks [16,17].

Based on the above reasons, this paper proposed a method of using gangue and tailings as substitute materials. Gangue is one of the commercially worthless materials that surrounds, or is closely mixed with, a wanted mineral in an ore deposit. Usually, gangue can be separated as waste rocks before mineral processing, which are suitable as aggregates. Tailings are the materials left over after mineral processing process and often finely ground for extracting the valuable fraction from the ore, which are chemically similar to natural clay and can be used as high temperature binders. In current practice, gangue and tailings are disposed of in tailing pond or backfilled in the mines without effective utilization. Those disposal ways waste the associated resources, occupy vast land and lead to potential environmental and safety problems, including but not limited to contamination of surface water, groundwater and soils, and failure of tailings dams [18–20]. Researchers have studied the utilization of different types of gangue or tailings to produce construction and building bricks [21–23]. However, the study about the fabrication of permeable brick from gangue and tailings is rarely seen.

Our research adopted sintering method to produce permeable bricks and simplified the method without using natural clay and artificial aggregates. This not only saves the energy consumption of the production of artificial aggregates, but also reduces the use of natural clay. In our experiments, the gangue acted as aggregates for permeable bricks, and the tailings served as a high temperature binding agents. The effects of aggregates content, aggregates size, sintering temperature and adding new aggregate on the permeability, apparent porosity, water absorption and mechanical properties of the prepared permeable bricks were systematically investigated.

2. Materials and methods

2.1. Materials

Gangue and tailings used in our investigation were presented as gravels and powder, respectively. These two raw materials were both received from a feldspar mine in Anhui Province, China. First, they were dried at 105 °C for 12 h in an electrically heated drying cabinet in order to remove the moisture. Before the tailings were used for the subsequent sintering experiments, they were ground to break the agglomeration of powder and sieved to an aggregate size <0.074 mm. Similarly, gangue was ground and sieved to different aggregate size portions, in order of size, 0.425–0.85 mm, 0.85–1.18 mm, 1.18–2.0 mm, 2.0–2.36 mm and 2.36–4.0 mm. In addition, the chemical compositions (wt%) of these two raw materials are tested by the X-ray Fluorescence (XRF), and the results are shown in Table 1.

The crystalline phases were identified by using X-ray diffraction (XRD), and the XRD patterns of gangue and tailings are shown in Fig. 1. It can be seen that, the gangue and tailings have the similar crystalline phases, containing quartz, albite and microcline, respectively.

2.2. Sample preparation

In this study, the gangue and tailings were mixed in different proportions and added about 10 wt% water to increase the forming property. Here, the proportions of the raw materials were shown in Table 2. The homogenized mixtures then were pressed into a brick (100 mm × 200 mm × 50 mm) under a pressure of 2 MPa. Afterwards, the obtained green bricks were transferred to an oven and were dried at a temperature of 100 °C in ambient conditions for 12 h. Subsequently, the dried brick samples were fired in a laboratory type electrical furnace at a temperature range of 1100–1200 °C with the heating rate of 2.5 °C/min to 750 °C, and 3 °C/min to predetermined temperature. After firing at desired temperature for 45 min, bricks were cooled to room temperature by natural convection inside the laboratory electrical furnace.

Moreover, the samples for permeability test were cut into cylinders of Φ75 mm × 50 mm and were determined by a tester given in national standard GB/T 25993-2010 [24] for permeable bricks, which is a constant water head apparatus by applying Darcy's law. In addition, the compressive strength of the fired samples was measured by using a universal testing machine (Suns Shenzhen, China) with a crosshead speed of 2 mm/min. Then, the apparent porosity was measured according to the Chinese standard GB/T 2997-2000 [25].

The morphology of sintered permeable bricks was examined by Scanning electron microscope (SEM, S-4800, Hitachi). The crystalline phases in the raw materials and prepared bricks were investigated by X-ray diffraction using Rigaku D/max 2550PC X-ray (Cu-K α, scanning rate: 8°/min, scanning range: 10–80°).

3. Results and discussion

3.1. Effect of aggregates content

Fig. 2 shows the evolution of permeability, compressive strength and apparent porosity of permeable bricks sintered at 1180 °C with different content of gangue (aggregate size 1.18–2.0 mm). It can be seen that both of the permeability and apparent porosity increase with the increase of gangue content. It is interesting to note that when the content of gangue was as high as 90 wt%, the permeable bricks exhibited a water permeability of 0.085 cm/s, which is much higher than national standard (0.01 cm/s).

What's more, a good positive correlation between permeability and apparent porosity can be observed obviously. Apparent porosity is an important factor in making high water-permeable bricks. Generally, permeable bricks with a higher apparent porosity typically have a higher water permeability, which is attributed to that there are more connected pores and cavities in a compacted block for the flow of water.

Basically, the compressive strength decreases with the increasing gangue content. The compressive strength reaches a peak of nearly 40 MPa with 60 wt% gangue addition and decreases dramatically to 20 MPa when the content of gangue is 70 wt%. Finally, the compressive strength drops to 5 MPa accompanied a highest water permeability of 0.085 cm/s when the gangue content increased to 90 wt%. Apparently, the compressive strength shows an adverse tendency because of the negative correlation between permeability and compressive strength. It can be reasoned that open pores and channels in the bricks contribute to the permeability but diminish the physical strength of bricks.

In the sintering process of permeable bricks, gangue plays a role of coarse aggregate to create pores and channels for water to infil-

Table 1
The chemical compositions (wt%) of gangue and tailings.

Raw materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	SO_3	MnO	LOI
Gangue	73.31	14.33	1.49	1.53	0.36	4.17	4.23	0.19	0.01	0.02	0.36
Tailings	69.26	17.21	2.40	2.00	0.86	2.85	4.37	0.35	0.03	0.04	0.63