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Performance evaluation of asphalt mixture using brake pad waste as mineral filler

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HIGHLIGHTS

- Brake pad waste (BPW) used as mineral filler in asphalt concrete.
- Hamburg wheel tracking and semi-circular bending tests conducted.
- Anti-moisture and anti-rutting properties improved by BPW powder.
- Asphalt mixture with BPW powder has longer fatigue life.

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ABSTRACT

The failed brake pads have been recognized as a kind of solid waste, which result in serious environmental problem. In order to provide an approach for treating the brake pad waste (BPW), this paper investigated the feasibility of using BPW as mineral filler in asphalt mixture. Firstly, BPW was laboratory manufactured into powder with a size lesser than 0.075 mm. Then, the effect of BPW powder on the physical and rheological properties of asphalt mortar was studied by the softening point test, the penetration test, the rotation viscosity test, and the dynamic shear rheological (DSR) test. The results showed that the addition of BPW powder could improve the viscosity and high temperature performance of asphalt mortar. Finally, the influence of BPW powder on the mechanical properties of asphalt mixture was analyzed by the Hamburg wheel tracking test, the accelerated freezing-thawing test, the dynamic uniaxial compression test, the semi-circular bending test and the four-point bending fatigue test. Although the low temperature property of WBP mixture was worse than the control asphalt mixture with limestone filler, BPW mixture has better anti-moisture, anti-rutting and fatigue properties. Asphalt mixture containing BPW filler showed satisfactory performance improvement.

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1. Introduction

From the safety point of view, failed brake pads are common consumable of the prosperous automobile industry [1]. For instance, it is recommended to replace the brake pads of heavy duty trucks at least once a year. Generally, the weight loss of failed brake pad is about 40% compared to a new pad. For a biaxial wheel truck, the failed brake pads generated by a single replacement could be 35 kg. Since the global production of heavy-duty vehicles are 3.7 million per year, it is estimated that annual increment of brake pad waste (BPW) would be 129 thousand tons with just the new heavy-duty vehicles to be considered [2].

Unfortunately, failed brake pad could not be degraded naturally, which would cause enormous space waste and environmental pollution. The typical semi-metallic brake pad, has gained a considerable proportion in the international market due to its reliable performance, convenient maintenance and inexpensive cost [3]. Studies on the brake pad mainly focused on the development of new materials [4], such as microstructure analysis [5], mechanical behavior [6], wear performance [7], noise reduction [8] and environmental protection [9–11]. However, few studies have been conducted on recycling the BPW.

Hot-mix asphalt (HMA) consists of asphalt, mineral filler, coarse and fine aggregates. In recent years, construction and maintenance of HMA pavement have consumed large amount of non-renewable resources [12]. Therefore, many researchers are dedicated to explore alternative materials for the purpose of substituting natural mineral aggregate and filler, such as oxygen furnace slag [13,14], demolition waste [15], fly ash [16,17], biomass ashes [18], etc. It is widely recognized that utilization of recycled wastes

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is a promising way to reduce the demand for natural resources in asphalt mixture.

In addition, previous studies have investigated the effect of steel slag, rubber particle, fiber and graphite on the mechanical properties of asphalt mixture. The steel slag used as coarse aggregate could improve the mechanical and electrically conductive properties of asphalt mixture [19]. The rubber particle could also improve the mechanical properties of asphalt at high and low temperatures, and prolong the durability of pavement [20]. Fiber has a reinforcing and toughening effect on asphalt mixture, which results in a significant improvement of Marshall stability, rutting resistance, indirect tensile strength, and low temperature cracking resistance compared to conventional asphalt mixture [21]. Graphite powder could improve the thermal conductivity and anti-ageing property of asphalt binder [22]. Generally, brake pads are composed of various components, e.g. metal powder, rubber, fiber and graphite, etc. in order to improve the wear resistance and structure stability [23]. Since such materials also help to improve the performance of asphalt mixture, it is assumed that the brake pad waste could be used as road material and is of high potential to improve the properties of asphalt mixture. Meanwhile, utilization of BPW could also make a considerable contribution to mitigate the environment pollution problem. However, few literature are found to investigate the effect of BPW materials on the mechanical properties of asphalt mixture.

The objective of this research is to study the feasibility of using BPW in asphalt mixture. Firstly, the BPW was laboratory manufactured into powder for substituting the mineral filler in asphalt mixture. Then, both asphalt mortar and asphalt mixture with different content of BPW powder were prepared. And the effect of BPW powder on the physical and rheological properties of asphalt mortar was investigated by the softening point test, the penetration test, the rotation viscosity test, and the dynamic shear rheological (DSR) test. Moreover, the influence of BPW powder on the performance of asphalt mixture was evaluated by the Hamburg wheel tracking test, the accelerated freezing-thawing test, the dynamic uniaxial compression test, the semi-circular bending test and the four-point bending fatigue test.

2. Materials and experimental method

2.1. Raw materials

Basalt with the particle size lesser than 19 mm was obtained from Hong'an County, Hubei Province, China. The 60/80 penetration graded asphalt binder, obtained from the SK Co., Ltd. in Korea, with a softening point of 47.2 °C (ASTM D36) [24], a ductility of 156 cm (25 °C, ASTM D113) [25] and a penetration of 73 dmm (deci-millimetre, 25 °C, ASTM D5) [26], was used for this research. Limestone filler has a particle size of lesser than 0.075 mm and a density of 2.88 g/cm^3. Characteristics of aggregates and asphalt binder were tested according to ASTM and AASHTO standards.

BPW was obtained from the local truck garage in Wuhan. It was a kind of semi-metallic brake pad with arc shape. In this study, the BPW was processed into powder (lesser than 0.075 mm) by three steps. Firstly, recycled BPW was broken into coarse particles with different sizes less than 20 mm. Secondly, all the BPW particles were put into the Los Angeles abrasion tester for further crushing. Thirdly, the BPW powder with a particle size lesser than 0.075 mm was obtained by screening the BPW particles obtained in step 2. The BPW powder has a density of 2.79 g/cm^3.

Based on X-Ray Fluorescence analysis, the chemical composition of BPW powder was seen in Table 1. Loss on ignition mainly consists of the resin binder and the graphite. The oxidation of silica and calcium accounted for the main component, which can change the microstructure of asphalt mortar and bring useful characteristics such as high absorptive and chemical stability [18].

Table 1
Chemical composition of BPW powder.

Component	Proportion (%)	Component	Proportion (%)
Loss on ignition	36.946	TiO_2	0.292
SiO_2	21.558	ZnO	0.178
CaO	14.038	SrO	0.083
MgO	7.139	Cl	0.081
Fe_2O_3	5.804	MnO	0.08
Al_2O_3	4.963	P_2O_5	0.054
SO_3	3.833	ZrO	0.044
BaO	3.229	CuO	0.041
K_2O	0.555	NiO	0.034
Na_2O	0.545	As_2O_3	0.009
Cr_2O_3	0.489	PbO	0.006

2.2. Sample preparation and mix proportions

In order to prepare asphalt mortar specimen, asphalt binder (200 g ± 5 g) was preheated to 165 ± 5 °C in an oil-bath heating container. Then, limestone filler (LF) and BPW powder were separately added slowly within 10 min, while the shear speed was kept at 2000 rp/m. After all the mineral filler and BPW powder were added, the asphalt mortar was sheared for another 30 min to make sure the homogeneously dispersing of additives in the asphalt. Table 2 presented the material composition of different asphalt mortars. In this study, three test repetitions were used for all the performance tests of asphalt mortar in Section 2.3, and the average value was used.

Superpave procedure was adopted to design a mixture with the nominal maximum size of 12.5 mm in this research. The gradation curve of Superpave 12.5 was shown in Fig. 1. The upper and lower limits of gradation curves followed to the Superpave Specification AASHTO M323 [27]. The optimum bitumen content of asphalt mixture was 4.9% by weight of asphalt mixture, which was determined by the volume parameters (e.g. air void, voids in mineral aggregate VMA, and voids filled with asphalt VFA). The content of mineral filler was 3% by weight of aggregate. Table 2 also illustrated the mixture proportions by weight sum of Superpave design specimen (Φ150 mm × h115 mm). In this study, six test repetitions were used for all the performance tests of asphalt mixture in Section 2.4, and the average value was used.

2.3. Performance tests of asphalt mortar

2.3.1. Physical properties tests

The physical properties of asphalt mortar, including softening point, penetration (25 °C), and rotation viscosity (135 °C and 175 °C) were tested according to ASTM D36, ASTM D5, and ASTM D4402 [28], respectively.

2.3.2. Dynamic shear rheological test

The dynamic shear rheological (DSR) test was applied to characterize the rheological properties of the asphalt mortar according to AASHTO T315 [29]. High temperature sweep test was performed under strain-controlled mode with a constant frequency of 10 rad/s. The testing temperature ranged from 30 °C to 80 °C.

2.4. Performance tests of asphalt mixture

2.4.1. Hamburg wheel tracking test

Hamburg wheel tracking test (HWTT) was proposed to evaluate the moisture susceptibility of asphalt mixtures according to AASHTO T324 [30]. The size of HWTT specimen was 150 mm in

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