Construction and Building Materials 160 (2018) 707–713

Contents lists available at ScienceDirect

Construction and Building Materials

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

Performance enhancement of porous asphalt pavement using red mud as alternative filler

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HIGHLIGHTS

- Rheological and raveling properties of asphalt mortar and porous mixture with red mud were evaluated.
- Larger filler-bitumen ratio leads to improved raveling resistance and lower permeability of porous asphalt mixture.
- Porous asphalt mixture with red mud shows excellent rutting, raveling and aging resistance.
- Red mud can be used as an alternative filler of limestone powder.

ARTICLE INFO

Article history:
Received 24 September 2017
Received in revised form 15 November 2017
Accepted 19 November 2017

Keywords:
Porous asphalt pavement
Asphalt mortar
Red mud
Adhesion
Rutting
Raveling

ABSTRACT

Porous asphalt pavement material is a special asphalt mixture with a void content of 18% or more. The porosity is essential to the ecological functions of porous asphalt pavement, i.e., water drainage, noise reduction, water purification. However, the porous structure of pavement also has caused some structural defects. Rutting, raveling and void clogging hindered its popularization in heavy-load and high-speed field. The major cause of the raveling and rutting is the temperature sensitivity and a lack of adhesion of asphalt mortar, especially under repeated heavy load from vehicles. Firstly, this study prepares six types of asphalt mortar including two types of fillers (limestone powder and red mud) and three filler bitumen ratios (0.3, 0.6, 0.9). Secondly, the rheological properties of asphalt mortar are investigated through Brookfield Viscosity, Superpave high temperature binder criteria $G^*/\sin\delta$, Multiple Stress Creep Recovery and Bending Beam Rheometer. Thirdly, this study investigated the effect of filler type and filler-bitumen ratio (FB ratio) on the air void, permeability, adhesion performance and raveling resistance. Finally, Hamburg Wheel Tracking Test and three types of Cantabro Tests (standard, water immersion and aging) are performed to confirm that the raveling and rutting resistance performance of red mud is better compared to the widely used limestone powder. The results indicate that the performance of porous asphalt with red mud filler at 0.9 FB ratio exhibited enhanced performance for raveling and rutting resistance.

1. Introduction

Porous asphalt (PA) pavement, in the beginning also be called as open-graded friction course (OGFC), has been used since 1950s in different areas of the United States to reduce traffic noise and improve the surface frictional resistance [1]. It improves wet weather driving conditions by draining the water away from the roadway surface through its porous structure. The improved surface drainage reduces hydroplaning, reduces splash and spray behind vehicles, improves wet pavement friction and reduces traffic noise [2]. However, many states stopped using porous pavement due to the inferior performance and lack of adequate durability, i.e., rutting, raveling and pore clogging [3]. Significant improvements have been made in the porous asphalt pavement during the last few years in the gradation and binder type, especially the development of high viscosity polymer modified asphalt [4]. However, the large amount of pores dramatically reduces the strength and durability of porous asphalt pavement which is reflected by its vulnerability to rutting and raveling, that is, the loss of stone from the pavement surface. Raveling, a type of failure that finds its cause within the stone-to-stone contact region, is a

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https://doi.org/10.1016/j.conbuildmat.2017.11.105
0950-0618/

dominant defect of porous asphalt pavement resulting in frequent road distress like pit slot and rutting. Therefore, compared with the traditional dense-graded asphalt mixtures that have a service life of approximately 18 years, the average service life of porous asphalt mixtures is limited to 10–12 years even shorter [5]. Usually, the porous asphalt pavement is just limited to the application of sidewalk, eco-park, parking lot and areas with light traffic [2].

According to the research by L.T. Mo [6], the raveling of porous asphalt pavement usually happened at the stone-to-stone contact region due to a lack of adhesion of asphalt mortar rather than just asphalt binder itself. Mineral fillers could change the rheological properties of asphalt binder so that they play a crucial role in the adhesion between aggregate, not just the volume-filling effect in asphalt mixture [7–9]. In the early development of porous asphalt pavement, to pursue the large porosity and the excellent ecological functions (noise reduction, drainage, anti-skid, etc.), usually a very small amount of mineral powder filler has been used in the design of mixture. Thus, it leads to the raveling distress at an early stage [2]. As a consequence, it is important to deeply investigate the mortar's effect on porous asphalt pavement.

Nowadays, natural resources are depleting worldwide, while at the same time the wastes generated from the industries are increasing substantially. Red mud generated out of Bayer's process for alumina production from Bauxite is a high volume solid waste [10]. In China, the production of 1-ton alumina will produce 0.8–1.5 ton red mud, depending on the mineral property, production methods and technical level. Most of red mud in China is concentrated in Shandong, Henan, Guangxi, Shanxi, Guizhou. In 2011, China's red mud output is about 70.0 million ton, what's more the cumulative stockpile is about 400 million ton. A large number of red mud is difficult to get full and effective use. Furthermore, traditional stockpiling and landfill not only pollute the environment but also cause a waste of resources. Hence, the exploitation and utilization of red mud resources have attracted growing attention of all countries in the world.

Due to its chemical composition, the red mud can be applied as an alternative material in the construction industries. According to the research conducted by M. Ramesh [11], red mud can be used in the production of cement mortar and bricks. In addition, red mud improves the cement properties and compressive strength in the way of reducing the setting time. However, very few studies have been recently performed on the application of red mortar as filler in porous asphalt pavement around the world.

This study investigated the effect of filler type (Limestone powder and red mud) and the ratios (0.3, 0.6, 0.9) on the rheological properties of asphalt mortar, including Brookfield Viscosity, Superpave high temperature binder criteria $G^*/\sin\delta$, Multiple Stress Creep Recovery (MSCR), Bending Beam Rheometer (BBR) [12–14]. Then the optimal filler-bitumen ratio (FB) in this study was chosen through the comparison of raveling resistance and permeability of Porous Asphalt (PA) mixture with different filler binder ratio. The raveling and rutting resistance were explored using Hamburg Wheel Tracking Test (HWTD) and three types of Cantabro Tests (standard, water immersion and aging). The possibility of red mud used as alternative filler in porous asphalt pavement was also analyzed.

2. Materials and methods

This study used SBS modified asphalt produced in Guangzhou, China. The SBS content is 8%. Its properties are shown in Table 1. The two types of filler used in this research were limestone powder and red mud obtained from the aluminum industry in Henan province, China. The properties of these materials are shown in Table 2.

During the preparation of porous asphalt mixture, two types of aggregates were selected, of which basalt and limestone were used as coarse aggregate (≥4.75 mm) and fine aggregate (<4.75 mm) respectively.

FB usually changes in the range as in actual construction. In Superpave asphalt mixture design code, FB range is advised from 0.8 to 1.6. However, this is suitable for the dense gradation asphalt mixture [15]. When it comes to open gradation asphalt mixture like PA mixture, the FB is usually lower. In order to analyze the influence of filler type and filler bitumen ratio, mortar's rheological properties of two type of fillers with different FB (0.3, 0.6, 0.9) were tested. The preparation procedures of asphalt mortar are listed as follows,

1) Asphalt binder was first heated up to 185 °C till it became liquid.
2) A corresponding amount of filler according to FB was added in three times with equal amount, while a 5-min shearing procedure using an agitator with a shearing rotor was applied at 185 °C after each adding; the shearing speed is 4000 r/min and the total shearing time is 15 min.
3) Rheological properties of these mortar should be tested immediately.
4) The storage time of these mortar shouldn't exceed one week to prevent segregation. Within one week, before using these mortar to conduct rheological properties, a 5-min stirring procedure should be applied at 185 °C for 5 min, and the stirring speed is 500 r/min.
5) To eliminate the effect of shearing procedure on the comparison of rheological properties between asphalt and asphalt mortar, the asphalt also was sheared at 185 °C with a speed of 4000 r/min for 15 min.

Rheological tests conducted for high viscosity asphalt and asphalt mortar were Brookfield Viscosity (ASTM D4402), Superpave high temperature binder criteria $G^*/\sin\delta$ (AASHTO TP 5), MSCR (AASHTO TP 70-10), BBR (AASHTO M320). In addition, binder bond strength (BBS) test (AASHTO TP-91) was used to study the adhesion performance of high viscosity asphalt and asphalt mortar used in this study.

3. Experiments

To determine the effect of filler type and ratio on the performance of PA mixture, a series of PA mixtures were prepared in the laboratory with different filler types and FB corresponding to the mortar. OGFC-13, widely used as PA upper layer in China, was chosen for investigation in this paper. In the PA mixture

Table 1
High viscosity asphalt properties.

Test item		Unit	Specifications	Results
Penetration@25 °C, 100 g, 5 s		0.1 mm	20–40	38
Penetration Index		–	≥0.0	+0.17
Ductility@5 °C, 5 cm/min, cm		cm	≥20	22
Softening Point, $T_{R\&B}$		°C	≥82	93.5
Flash Point		°C	≥230	326
Solubility		%	≥99	99.8
Storage Stability@163 °C, 48 h, Difference between softening point		°C	≤2.5	2.0
Elastic Recovery@25 °C		%	≥95	95.1
RTFOT Residue (163 °C, 85 min)	Weight Change	%	±1.0	+0.01
	Ductility@5°C, 5 cm/min	cm	≥15	16
	Penetration Ratio	%	≥70	73.7
Dynamic Viscosity @60 °C		Pa·s	≥20,000	709,875
SHRP PG		–	PG 76-22	PG 76-22